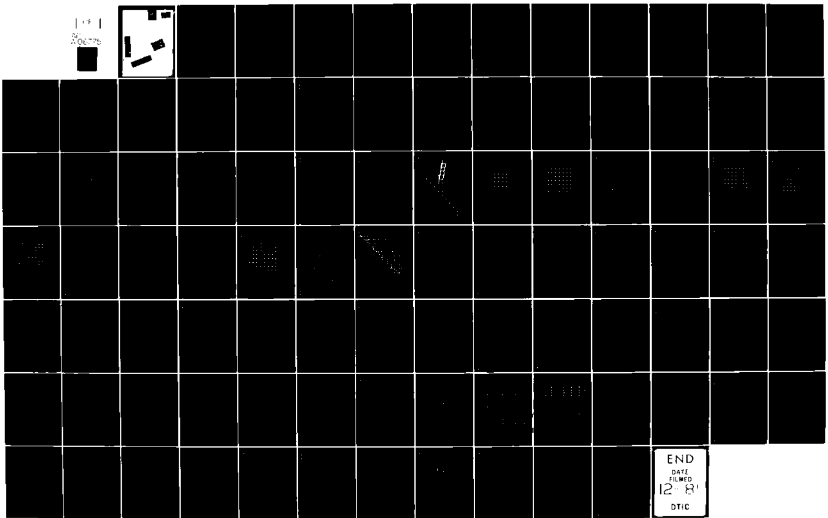
AD-A106 775   ILLINOIS UNIV URBANA DEPT OF ARCHITECTURE   F/G 5/1
FORMAL TECHNIQUES FOR ANALYSIS AND DESIGN OF PURPOSIVE ORGANIZA--ETC(U)
SEP 81   E L MURPHREE, R M DINNAT, P CLICKENER   AFOSR-80-0090
UNCLASSIFIED   AFOSR-TR-81-0711   NL



LEVEL II

(12)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR-81-0711	2. GOVT ACCESSION NO. AD-A106	3. RECIPIENT'S CATALOG NUMBER 775
4. TITLE (and Subtitle) FORMAL TECHNIQUES FOR ANALYSIS AND DESIGN OF PURPOSIVE ORGANIZATIONS.		5. TYPE OF REPORT & PERIOD COVERED Final ~~Report~~
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. L. Murphree, Jr ~~PhD~~; R. M. Dinnat PhD; Patricia Clickener Richard Matthews		8. CONTRACT OR GRANT NUMBER(s) AFOSR-80-0090
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Architecture University of Illinois, Urbana-Champaign Urbana, IL 61801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2313 A3
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research (NL) Bolling Air Force Base, D. C. 20332		12. REPORT DATE Sept ~~ember~~ 1981
		13. NUMBER OF PAGES 90
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Organization theory; formal organization; organization analysis; mathematical models; organization charts; systems analysis; management; personnel management.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A framework for a generic model of purposive human organizations is presented. The static model is based on relationships between pairs of resources, pairs of tasks, and resource-task pairs. The heart of the approach is a relational matroid which allows notations of such basic organizational patterns as authority, groupings of resources, task precedence, assignment of resources to tasks, and information flow.

412616

DD FORM 1 JAN 73 1473

Unclassified

86

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Formal Techniques

for

Analysis and Design of Purposive Organizations

FINAL REPORT

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

E. L. Murphree, Jr., PhD
R. M. Dinnat, PhD
Patricia Clickener
Richard Matthews

of the
Department of Architecture
University of Illinois, Urbana-Champaign

for the
U. S. Air Force Office of Scientific Research
Bolling Air Force Base
Washington, D. C.

Grant #AFOSR-80-0090

September 1981

E. L. Murphree Jr.
R. M. Dinnat
P. A. Clickener
Richard Matthews

Acknowledgements

This report was prepared under the sponsorship of the U. S. Air Force Office of Scientific Research, Bolling Air Force Base, Washington, D. C., under Contract #AFOSR-80-0900, dated 1 February 1980.

Program Manager for this project was Dr. Alfred R. Fregly, Life Sciences Division, AFOSR.

Formal Techniques

for

Analysis and Design of Purposive Organizations

Final Report

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Formal Techniques
for
Analysis and Design of Purposive Organizations

1. Summary

The design of purposive organizations is perhaps the most complex of human undertakings. There is little in the way of formal design methodology to guide the organization designer or the diagnostician faced with an apparent organizational dysfunction. Tradition and experience have been the bases for structuring even organizations expected to perform unprecedented missions. Much has been done, however, on design methodology for highly complex computer and communications systems design. The study reported herein has shown that many of the important features of human organizations can be documented in the formal notation of modern systems, matrix algebra, and used to advantage by the organization designer.

The readily understood tabular format of matrices allows one to plot in graphic form the patterns of such diverse organizational structures as authority; assignment of workers to tasks; groupings of workers or other resources into crews, teams, committees and the like; flow of information and partially completed work from task to task; and feedback of effects of performing tasks to the workers involved. The tabular patterns will be useful in the hands of trouble-shooters who seek to isolate causes for low morale, failing productivity, or other organizational dysfunction. And it will be useful to the

organizational designer faced with preparing an organizational structure and operational procedures to accomplish a new mission, for which no experience has been accumulated.

The most beneficial use of this developing technology of organizations, however, is likely to be the eventual ability to simulate, by means of digital computers, the probable performance of hypothetical organizations in the face of changing internal conditions (e.g., loss of equipment, manpower, communications) or external conditions (e.g., opposing forces, weather, support). While the present state-of-the-art does not support this kind of simulation, the work reported here is a step in that direction, and is encouraging that it is achievable.

The techniques reported here can support further steps toward computer-supported design of human purposive organizations. They can, at the same time, be used directly by organization design professionals as aids in documenting organization patterns and flows, diagnosing areas of dysfunction, and making recommendations for positive change.

The remainder of this report presents the details of a static model of human organization and the experimental work that has been done to verify that certain vital organizational features can be documented by the matrix format. It closes with an example of the use of the notation to depict organizational patterns of an existing architectural design firm.

2. Introduction

2.1. Background

A pervasive human activity is the design of organizations to accommodate to organizational purpose; the legal, economic, social, and political environments; and human and other resources. There is no body of formal procedures for the design of human organizations and the task is therefore done subjectively, drawing heavily on experience. Organizational structures of the past suggest those of the future. The typical approach has been to base new entities on stereotypical structures and make changes as problems are recognized. Clearly, this is not an optimal approach to bringing a viable organization into being. A design methodology supported by formal procedures and generalized models holds the potential for saving enormous amounts of time and money. The development of such an objective design methodology is the focus of the research program described here.

Research to date on organization design has followed, for the most part, a descriptive path, that is, the reporting on structural patterns that have proved successful in various contexts. Little has emerged thus far in the way of prescriptive techniques. On the other hand, an impressive literature has evolved which deals with design of highly complex computer and communications systems. Important analogies exist between control systems for industrial robots, artificial intelligence systems, multi-user interactive computer operating systems, translators for programming languages and the like on one hand, and complex human organizations on the other. This wealth of systems knowledge has not been systematically exploited for that most complex of human enterprises, the design of purposive human organizations.

The successful application of developments from other fields, however, requires first that a basic framework for the formal description of organizational structures be articulated and shown to be sufficiently comprehensive to incorporate the structures found in existing viable organizations. The second step is to devise operational techniques which can exercise the structural model in time. These two primary constructs, the structural model and its operational techniques, constitute the foundation of a comprehensive, integrated design and analysis system. The present research is aimed at producing such a basic working model, as a first major step toward a sophisticated yet practical design system for complex human organizations. A second product is sufficient insight into the real workings of modern organizations as to serve as diagnostic tools for aid in treating ailing organizations.

2.2. Long Range Goals

1. A general purpose simulation model for human organizations which will allow the formal description of the essential parameters of the organization (e.g., resources; tasks, relationships; information and product flows; task sequencing and scheduling; resource assignment and status; factors influencing the character of tasks and the performance of resources; procedures for task accomplishment; future plans; record of past performance of resources and sets of resources, i.e., an institutional memory; and versions of the conceptual organization as possessed by the various human resources); and provide the means to change and track all these parameters as they interact with each other and respond to external stimuli in time.

2. A formal language that will allow one to

   a. describe explicitly a hypothetical organization designed to carry out a set of interrelated tasks representing an assigned mission, or

b. describe an existing organization in order to examine its present functioning and to predict its functioning under internal and external change.

3. Data gathering techniques to allow one to efficiently collect reliable modelling parameters from organization participants, or the organization designer, if in a synthesis mode.

4. A multi-level simulation methodology ranging from pencil-and-paper through computer processing, to make it practicable to answer "what if" questions about the organizational response to internal and external stimuli such as change in mission, loss of resources, cut back in strength, and the like. The highest level of processing would be through an interactive computer processor, in real time.

5. An integrated and flexible organization design methodology to guide one in using effectively the collected data, the formal language, and the processors to develop an organization design with a high probabilit of success, and to respond rapidly with structural and operational modifications when confronted with material changes in internal or external conditions.

2.3. Typical Uses for the Methodology

The long range goal of this research is to produce practical management tools which are applicable in the entire spectrum of human organization, from the basic work group to executive level. Based largely on information flows and cybernetics, the technology can improve the vertical integration of policies and their implementation by emphasizing and tracking task decomposition and specialization from broad statements of intent to concrete steps ultimately required to accomplish the purpose. It can improve the horizontal integration of system requirements, (e.g., manpower planning, training, operational requirements, new weapons system acquisition) through the provision of a structural framework for coordinating information flows within agencies and between agencies. Following are some typical uses of the technology, in the context of military organizations. They are representative and not exhaustive.

1. Reaction by management to external stimuli:

   a. Reduction in force -

      The responsible manager, confronted with an impending reduction in force with no change in assigned mission, is required to alter his organization structure and task-processing functions to adapt to a reduction in resource availability. He will use the methodology to pose hypothetical organizational changes, note effects on productivity, revise his modifications, and repeat the process until the results are satisfactory or until it is clear that mission effectiveness or efficiency will be unacceptably degraded if the proposed reduction in force is implemented.

   b. Change in mission -

      The responsible manager will simulate the results of various alterations to the existing organization to determine the optimum reorganization. Alternatively, he may restructure the model organization to simulate response to changes in task sets and internal relationships to accommodate the new mission.

   c. Change in resource responsiveness -

      The responsible manager will redesign tasks to respond to recognized changes in human resource motivations, skill levels, etc.

d. Decrease in budget, mission unchanged -
The responsible manager will use the system to assess the effects of lowered financial resources on influencing factors or task elimination or modification (e.g., training exercises) on force readiness, effectiveness, and efficiency.

2. Effects on force readiness or performance due to various kinds of internal stimuli changes.

The responsible manager may use the methodology to study

a. effects on productivity and force readiness of variations in leave policy, retirement policy, work rules,

b. hypothetical response to variations in internal perception of external threats, or

c. degradation of response with internal psychological and/or physical attrition, i.e., organizational vulnerability/survivability studies.

2.4. The Research Program

The current research program of which the project reported herein is a part, is aimed at completing the conceptual design of the structural model and the mechanisms to make it operational, and verifying it through applications in existing organizations. The program is logically arranged in four phases.

1. The work in Phase I consists of verifying certain aspects of the basic structural model, specifically the nature of the relationships between resources and tasks, and pairs of tasks by on-site observation of the operation of an existing organization. The intent is to develop techniques

for gathering relational data from the organization's members and formally insert these data into the matrix model described elsewhere in this report. Patterns representing authority structure, ordering of basic tasks toward goals, and association of resources with tasks are to be demonstrated. A second objective of Phase I is to identify and document information flows for task accomplishment and for resource control. Finally, the model will be modified as required to enable it to embrace those aspects of organizational reality inelegantly handled in the elementary model.

2. The work in Phase II is aimed at providing for sequencing tasks and assigning resources to tasks, detecting task failures, making and modifying plans, and integrating individual job plans into a continually evolving long range operational plan for the entire organization.

3. The work of Phase III is to identify the influencing factors for resources and tasks and integrate them into the evolving model. It is this phase which promises to transform the basically mechanistic model into a sophisticated management tool which considers such factors as morale, health, fatigue, boredom, skill level and motivation and their impact on the effectiveness of the organization.

4. The intent of Phase IV is to extend the structural model to a simple dynamic model, able to simulate parametric changes over time while maintaining structural integrity. At this point, the model becomes a true simulator.

2.5. Current Status

Published results. The basic building block for a generalized structural model and an associated organization-building scheme have been articulated and documented in a recent symposium paper.[1] This elementary model is general enough to accommodate much of existing organization theory, yet is rich enough to support the structural definitions of complex organizations.

Unpublished results. Phase I of the present research has focused on (1) demonstrating the feasibility of modelling existing organizations in terms of the elementary model, and (2) establishing whether or not the model can serve as a useful diagnostic and design tool for managers. Work to date indicates positive results for both issues. In addition, the elementary model has been extended and made more powerful in terms of accommodating a richer definition of the structural and functional aspects of an organization. The current concept of the model, for example, includes provision for influencing factor vectors for resources and tasks; inter-relations between resources and tasks; and rudimentary machinery to allow the exercising of the model in time.

2.6. Relationship to Work by Others

No work directly related to the proposed research has been identified. Ansoff and Brandenburg,[2] in their description of a language for organization design, present the general structure of a variety of purposeful informally designed organizations, but have not prescribed a precedure for synthesizing organizational structure by formal means. Galbraith[3] has summarized the state-of-the-art in organization synthesis, but stops short of formal design methods. Dinnat and Murphree[4] have presented the basic elements of a formal organization model based on information flow theory, and have shown how such a model can serve as the basis for certain kinds of organization evaluation.

3. Objectives of the Project

3.1. Applicability of Model

A primary objective of the research project reported herein has been to demonstrate the feasibility of modelling existing organizations in terms of the model as it existed at the time the project was initiated; and, in the event that the model was inadequate, to identify changes to the structural elements of the model and the implementing techniques that would improve the effectiveness of the model as a diagnostic and design tool.

3.2. Diagnostics and Design

A second objective of the project has been to test the hypothesis that the analysis of the results of the describing process can be a useful diagnostic and design tool for managers. That is, independent of the generality of the formal model, does the process of describing an existing (or hypothetical) organization in terms of the model have a beneficial effect on the insight a manager has about the "workings" of his organization?

4. Approach

4.1. The Basic Model

4.1.1. Elementary Organizational Unit

The material in this section follows very closely that in Part 3, A Generalized Model of Organization Structure of Reference 5. It is included here to provide the reader with a historical perspective of the project as it was originally envisioned and as it evolved during the reported research.

The basic model as presented here allows much of an organization's structure to be graphically displayed. Both tasks and resources, including a management hierarchy for control, can be depicted. It also allows a clear display of some information inputs and outputs. There are, however, inherent shortcomings which will become evident in subsequent sections, and which compelled the re-casting of the format into a more powerful configuration.

It was this original format, however, that formed the basis for the planning of the project and for the initial steps in the field investigations.

4.1.2. Resources

The basic elements of which organizations are structured are the resources, which may be human workers; pieces of equipment; working space such as offices, conference rooms and industrial plants; or money. The resource class to which we relate most easily in the context of organizational structure is the human worker. Human resources are traditionally grouped together into coherent groups and the groups are structured according to some scheme aimed at focusing their work efforts on identifiable tasks, which themselves are structured in some fashion towards the accomplishment of certain goals. While traditionally resources have been organized into mutually exclusive hierarchical groups (i.e., the "pyramid" structure of the church and the military) for the primary purpose of establishing clear, unambiguous lines of authority and responsibility, variations on this pattern, notably matrix management,[6] are appearing, especially in high technology industries. A generalized model must provide a single framework within which the essential aspects of a great variety of organizations may be described, both structurally and operationally.

4.1.3. Tasks

An operating organization, then, may be viewed as a collection of resources performing a set of tasks, using selected procedures. Associated with each task and procedure are inputs, outputs, resources, and influencing factors, which are in some way time-dependent. In general, tasks are interdependent, either because output from one is the input to another or because more than one task must use the same resources.

4.1.4. Relationships

After elementary units of resources and tasks, the most vital tools of organization are relations. Indeed, the very essence of human organization is relationships between pairs of resources and tasks. The typical organization chart is a statement of authority relationships between pairs of organizational components. Figure 4-1 shows a hierarchy composed of an office of the Commander, a Legal Office, an Administrative Office and three Operating Units. Authority flows in the direction of the arrows. That is, the Office of the Commander is higher in authority within this organizational structure than any of the other organizational components. Expressed another way, the Office of the Commander has authority over the others.

Assignment of Captain Smith, Captain Jones and Captain Kirk, all attorneys, to the Legal Office relates each to each of the others in a "belonging to the same group" relationship, which tells us nothing about the authority structure (if one exists) within the group, i.e., the Legal Office. These are but two of the many important diadic resource relationships which make up the basic material of human organization.

Equally important are the relationships between resources and tasks (e.g., the assignment of a worker to do a particular task) and between pairs of tasks (e.g., the ordering of a set of tasks in a sequence so that a specific objective can be met). The totality of resources, tasks and pair-wise, or diadic, relationships constitute the reality of "the organization" at any given moment. A practical model must reflect this fact and allow the user to depict all the essential structural details he needs for the purpose at hand. The basic model described in the following section is aimed at fulfilling these requirements.

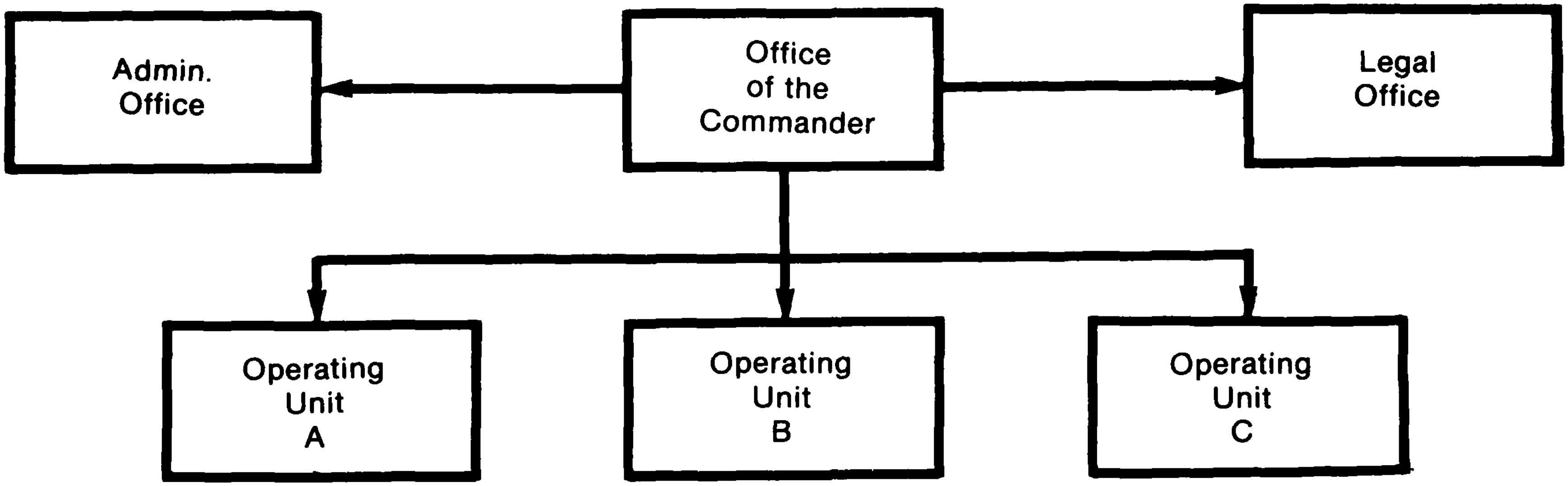

Admin. Office
Office of the Commander
Legal Office
Operating Unit A
Operating Unit B
Operating Unit C

Figure 4-1

4.1.5. Relational Matrix

The core of the basic model is a relational matrix (Figure 4-2) each row of which corresponds to a specific task performed normally by the organization, and each column of which corresponds to a specific resource or set of resources possessed by the organization. The diagonal element a_{ii} may by thought of as the "black box" of a simple input-output model (Figure 4-3) in which a selected procedure is being used to transform the input I into the output O.

Each output from task i is either input to another task j, or is output from the organization to its environment. For example, internal transfers between tasks might represent parts of a building design which is taking shape as various tasks are performed on it (say, design calculations, drafting, blueprinting, etc.), and transfer of output from a task to the outside might be the transmittal of a set of complete plans to the client. The important point here is that all flows between tasks, or between tasks and the external environment, are accounted for, with no inputs materializing from nowhere and no outputs left dangling, with no destination. An off-diagonal matrix element a_{ij} may be viewed as a communication channel or a queue into which output from task i can flow to task j, where it is to be used as input. Each row i, then, contains all possible output channels for task i and each column i contains all input channels for task i. The use of any channel a_{ij} denotes that an output-input relationship exists between task i and task j. (Note that no ordering of i and j is implied here.) The "operational connectivity" of an organization is thus displayed by its task-task relationship matrix.

Authority and responsibility relationships can also be displayed by means of matrix notation. These relationships fall into two groups: resource

		RESOURCES				
		1	2	3	4	5
TASKS	1	3	X		X	
	2		2	X	X	
	3			3	X	
	4		X		1	X
	5	X				1

Figure 4-2

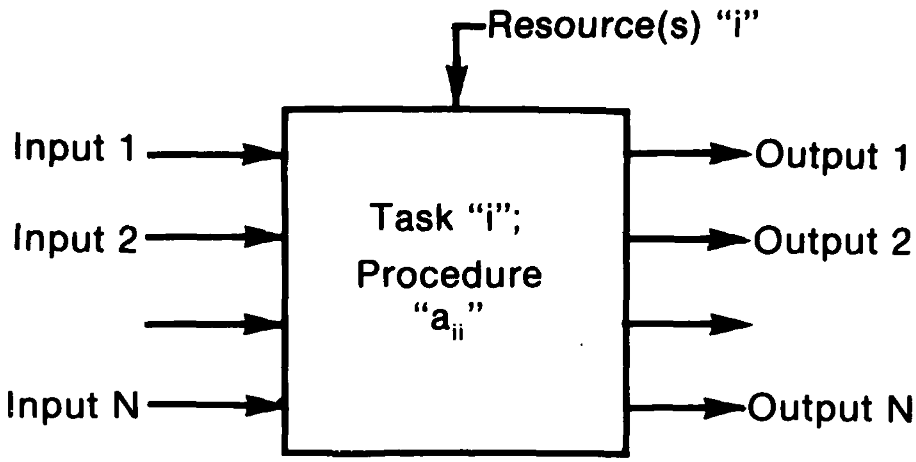

Resource(s) "i"
Input 1
Input 2
Input N
Task "i";
Procedure
"a_ii"
Output 1
Output 2
Output N

Figure 4-3

control and task control. Resource control implies the authority to commit resources and the responsibility for the quality of their performance. Task control implies the authority to identify and structure tasks and procure the resources for task accomplishment, and the responsibility for getting the task accomplished. Resources are placed under the control of a particular manager by assigning them to his organization element. In the relationship matrix (Figure 4-2) the resources are indicated by the columns. Grouping columns together under an organization title indicates that the resources represented by those columns are under the same manager's control (Figure 4-4).

Tasks are placed under the control of a particular manager by assigning him the authority to select the procedure to be used in performing a task and, via the authority to delegate funds, to select the source of the resources used in performing it. In the relationship matrix (Figure 4-2) the tasks are represented by the rows. Like column groupings, row groupings under an organizational title indicate single manager control and the level of the organization at which the decision authority rests.

In the pure hierarchical form of organization, both task control and resource control are vested in the same manager (Figure 4-5(a)). In the pure matrix form of management, task control and resource control are vested in different managers (Figure 4-5(b)). Hybrid forms of management, wherein there are varying degrees of separation of task and resource control, can also be represented by the matrix model as shown here. While some basic concepts and structure of human organizations can be displayed with the relational matrix of this section, there are inherent limitations which compel its modification. The following sections consider these limitations and present a transformed model which, while not fundamentally different from the original model allows more flexibility and fluency in presenting the patterns of both structure and operation.

4.2. The Transformed Model

4.2.1. Necessity/Justification

The basic model as presented in Section 4.1, above, has the limitation that only resource-task (R-T) relations can be expressly stated in terms of matrix elements. Organizationally vital relationships such as resource-resource (R-R) and task-task (T-T) relationships must be handled outside the matrix model, as in Figures 4-4 and 4-5(a) and (b). Neither resource groupings and authority structures, the very essence of organization, nor task sequencing, the foundation of purposeful organizational activity, can be handled directly by the matrix. There is a clear need for an expanded syntactic framework, within which a larger set of the observed elements of organization can be directly dealt with.

4.2.2. Structure of the Transformed Model

An examination of Figure 4-2 reveals that any element a_{ij} of the matrix can represent a relationship between resource R_i and task T_j. Expanding the rows of the matrix to include both tasks and resources (TUR) and the columns to include both resources and tasks (RUT), we have an expanded matrix whose columns and rows are identical (TUR≡RUT), and whose elements offer a substantially larger field for noting relationships. Figure 4-6 shows such an expanded relational matrix, the quadrants of which allow diadic relationships for R-T, T-T, T-R, and R-R, a far richer set of possibilities than with the matrix of Figure 4-2. The diagonal elements of this matrix imply a reflexive relationship of each R or T with itself. We discard the redundancy of labelled rows and columns to arrive at the

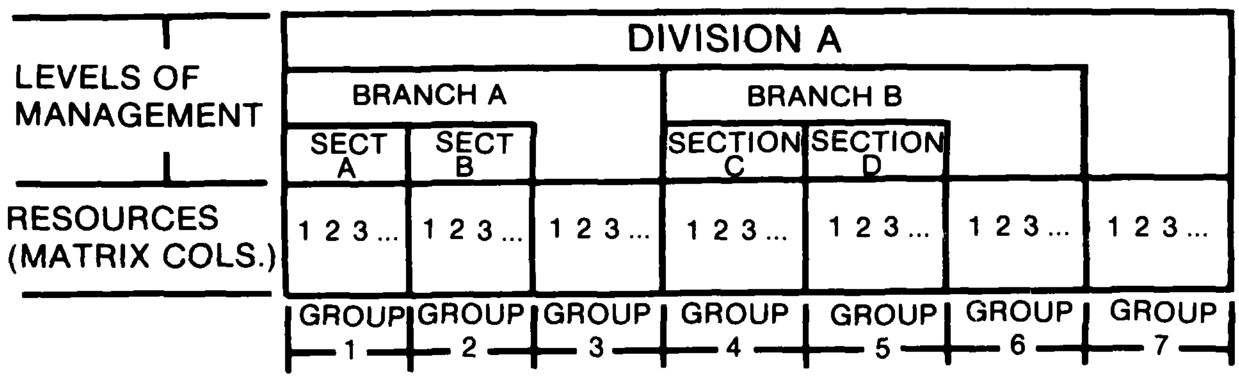

DIVISION A
LEVELS OF MANAGEMENT
BRANCH A
BRANCH B
SECT A
SECT B
SECTION C
SECTION D
RESOURCES (MATRIX COLS.)
1 2 3 ...
1 2 3 ...
1 2 3 ...
1 2 3 ...
1 2 3 ...
1 2 3 ...
1 2 3 ...
GROUP 1
GROUP 2
GROUP 3
GROUP 4
GROUP 5
GROUP 6
GROUP 7

Figure 4-4

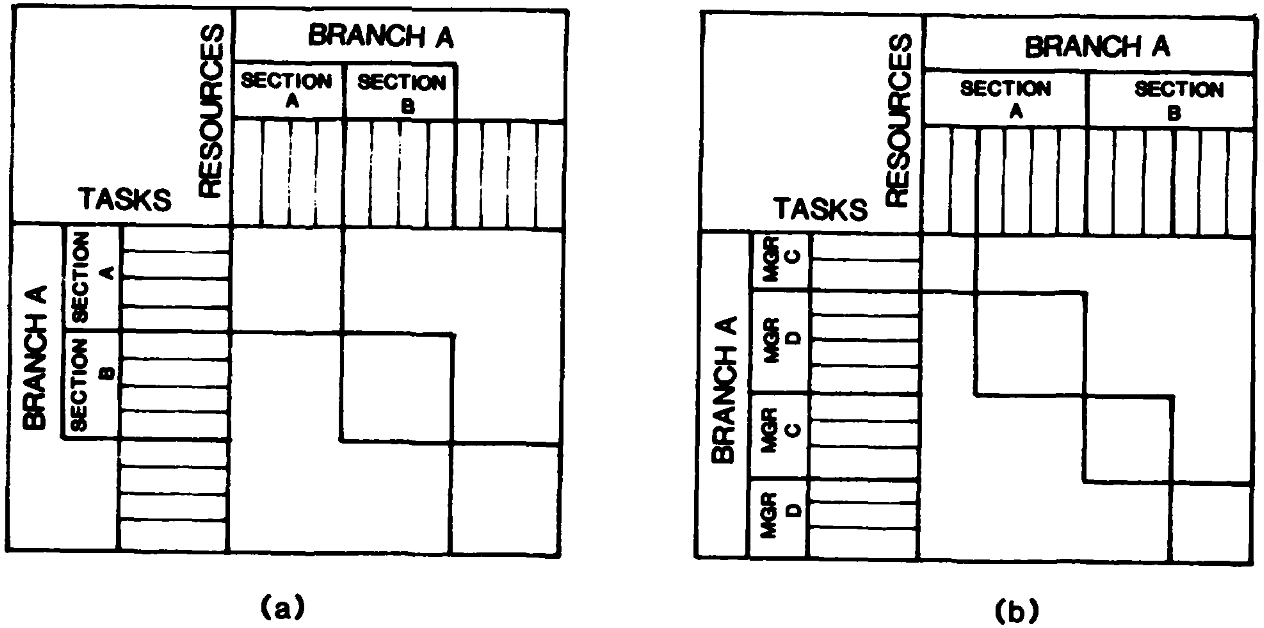

BRANCH A
SECTION A
SECTION B
RESOURCES
TASKS
BRANCH A
SECTION A
SECTION B
(a)
BRANCH A
SECTION A
SECTION B
RESOURCES
TASKS
BRANCH A
MGR C
MGR D
MGR C
MGR D
(b)

Figure 4-5

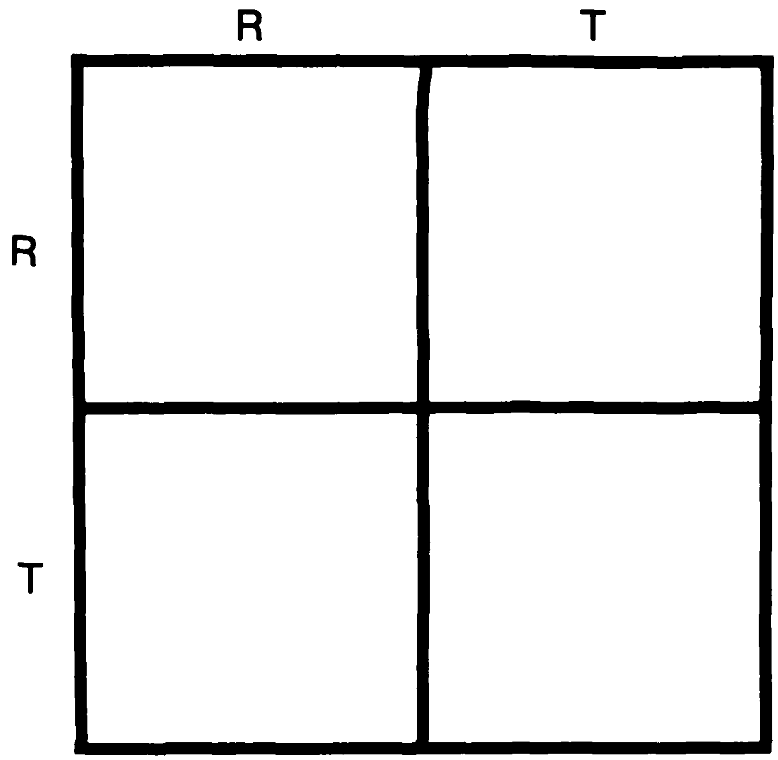


Figure 4-6
Expanded Matrix

transformed matrix S of Figure 4-7, the diagonal elements of which represent the resources R and tasks T of the organization. The off-diagonal elements represent the relationships of pairs of resources and tasks. A multiplicity of possible relationships between any (r,t) pair dictates that each off-diagonal element a_{ij} represent a vector of logical or numerical values. Since relationships can be permanent (e.g., "brother of") or ephemoral (e.g., "car-pools with"), the vector matrix S can be considered to be a state matrix, a snapshot in time of the organization of which it is a model.

4.2.3. Relationship to Basic Model

The expanded matrix S of Figure 4-6 contains as a subset the T-R matrix of Figure 4-2, and therefore is capable of handling all of the structures and patterns of the basic model. The transformed state matrix of Figure 4-7 contains all the information of Figure 4-6, and is, therefore, a super-set of it. The transformed diagonal state matrix of Figure 4-7 enhances the display of certain patterns and structures, beyond the capacity of the earlier forms. The next section describes these advantages.

4.2.4. Advantages of the Transformed Model

The transformed state matrix of Figure 4-7 allows the direct representation of relationships (e.g., superior-inferior, group membership) existing between any pair of resources (R-R relationships). With the basic model of Figure 4-4 and 4-5, these R-R relationships could only be represented off-matrix. Assignments of resources to tasks (R-T relationships), represented off-matrix in Figure 4-5, are directly represented in the transformed model. Relationships between pairs of tasks (T-T relationships), not represented at all in the basic model of Figure 4-2, may be represented

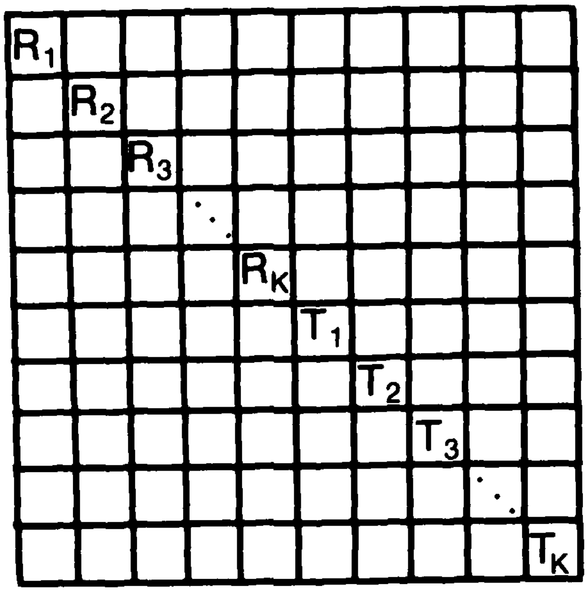


Figure 4-7
Transformed State Matrix S

directly in the transformed model, and task sets may take on such complex structures as non-planar partially ordered sets, the graph-theoretic basis of PERT and CPM, the foundation stones of modern project management. Each element in the transformed matrix S is a vector. We can consider, then, that the model is a 3-dimensional solid, each "layer" of which is a 2-dimensional matrix displaying the relationship patterns of a distinct relationship category. For example, one "layer" might show the authority relationships; another, the committee structure; and a third, assignments to tasks. Thus, the solid, "wired" matrix of relationships may be considered an analog of the "brain" of the organization at a point in time. That is, the relationships exist or are expected to exist for the interval in time t represented by the state matrix S_t, and will be changed at time t+1, and represented by S_{t+1}.

The transformed state matrix, then, opens up an enormous potential for directly representing the basic relationships between pairs of resources and tasks that collectively are the building blocks of human organization, and possibly of all organization. The next major section of this report defines and articulates those relationship patterns which have thus far been examined.

4.3. Relational Patterns

4.3.1. Definitions

4.3.1.1. Relationships and Notation

Of fundamental importance to the model is the concept of diadic relationships between resources, tasks, and resource-task pairs. Relationships form the "glue" that makes organizational structure possible. Specific relationship categories are defined and assigned a vector position in each matrix element. That is, matrix element S_{ij} represents a vector of values. The zth element in S_{ik}, i.e., s_{ikz}, may be assigned to represent the zth relationships (which might be defined as "supervisor of") in the relationship set. In Figure 4-8 this relationship between resource R_i and R_j is shown as an X in the zth position of the vector at s_{ik}. In the following discussion, it is convenient to consider the zth elements of the vectors s_{ik} as representing a 2-dimensional matrix, all elements of which represent solely the zth relationship. We are, in effect, considering the matrix S to be a book, in which each sheet, while structurally identical to the others, contains notations about only a single relationship class. That is, for example, a single sheet (matrix) will contain notations about authority relationships between pairs of resources. In the diagrams which follow, an X in a matrix position S_{ik} will indicate that the defined relationship exists between elements i and element k, as in Figure 4-9, which shows that R_1 is in an authority relationship over R_2, who is, in turn, in an authority relationship with both R_4 and R_5. The diagram tells us nothing about any other relationships which might exist between pairs of R's, nor does it convey any information about R_3. Neither does it directly display higher order authority relationships, such as the traditional transitive authority of R_1 over R_4 and R_5, with that authority passing through R_2.

4.3.1.2. Patterns

Within a single-level matrix, all relationships are of a single type or category. The collection of all such relationships in a single-level matrix totally define all the existing relationships of that category. For example, if the matrix of interest is that one assigned to "authority over," then it totally describes that relationship between all possible pairs of resources. The matrix as a whole, then, completely defines the authority structure of the organization, by the pattern of binary relationships. For example, in Figure 4-10, the pattern of X's is in 1-1 correspondence with the traditional organization chart of Figure 4-11.

4.3.2. Resource-Resource Patterns

4.3.2.1. Authority

The common notion of human organization is that it is an authority structure, accurately displayed by the "plumbing chart" of the typical hierarchically ordered organization, or its equivalent for variations of that arrangement. As any observant bureaucrat knows, however, the complexity of any real organization is barely glimpsed from its organization chart, which displays only the first order of authority. Authority is not without its limitations, too, and the extent of the real power implicit in authority assignments is defined in the context of each organization. The patterns of overt authority are discussed in Section 4.3.1.2, and constitute a syntactic structure of authority only. The meaning of the concept of authority, that is, its semantics, must be locally defined, off-matrix, and is useful primarily in expressing the model in a dynamic sense. Treatment of the meaning of authority is outside the scope of this study, but is, however, of paramount importance to the ultimate effectiveness of the model in organization design. It is sufficient here to agree that "authority over" is a relationship implying officially sanctioned control of one resource by another within the context of the organization's purpose. Authority is not synonymous with power, although elements of power are requisite for functional authority.

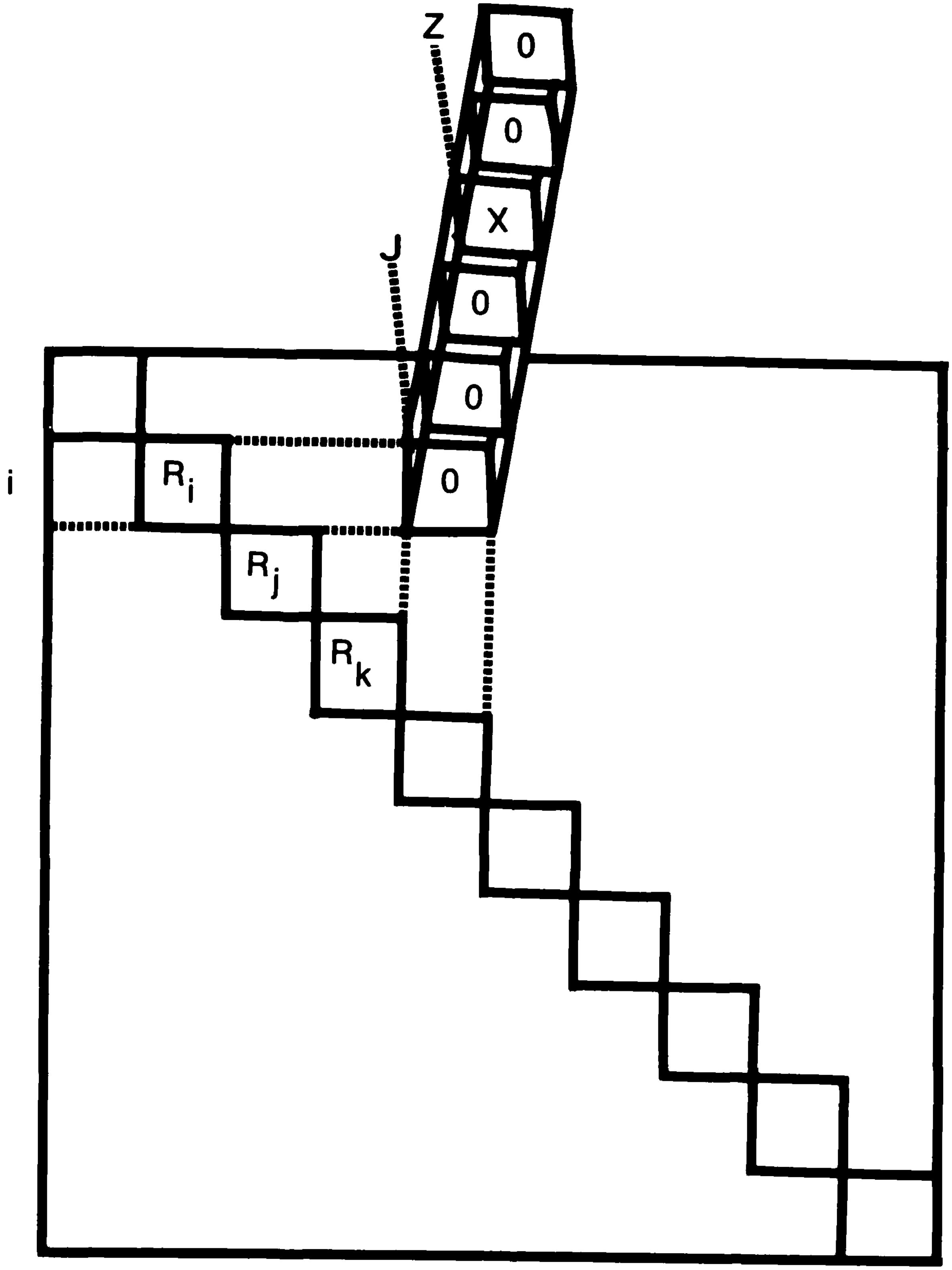


Figure 4-8

R_1	X			
	R_2		X	X
		R_3		
			R_4	
				R_5

Figure 4-9
Authority Relationships

R_1	X	X	X				
	R_2			X	X		
		R_3					
			R_4			X	
				R_5			
					R_6		
						R_7	X
							R_8

Figure 4-10
Matrix of Authority Relationships

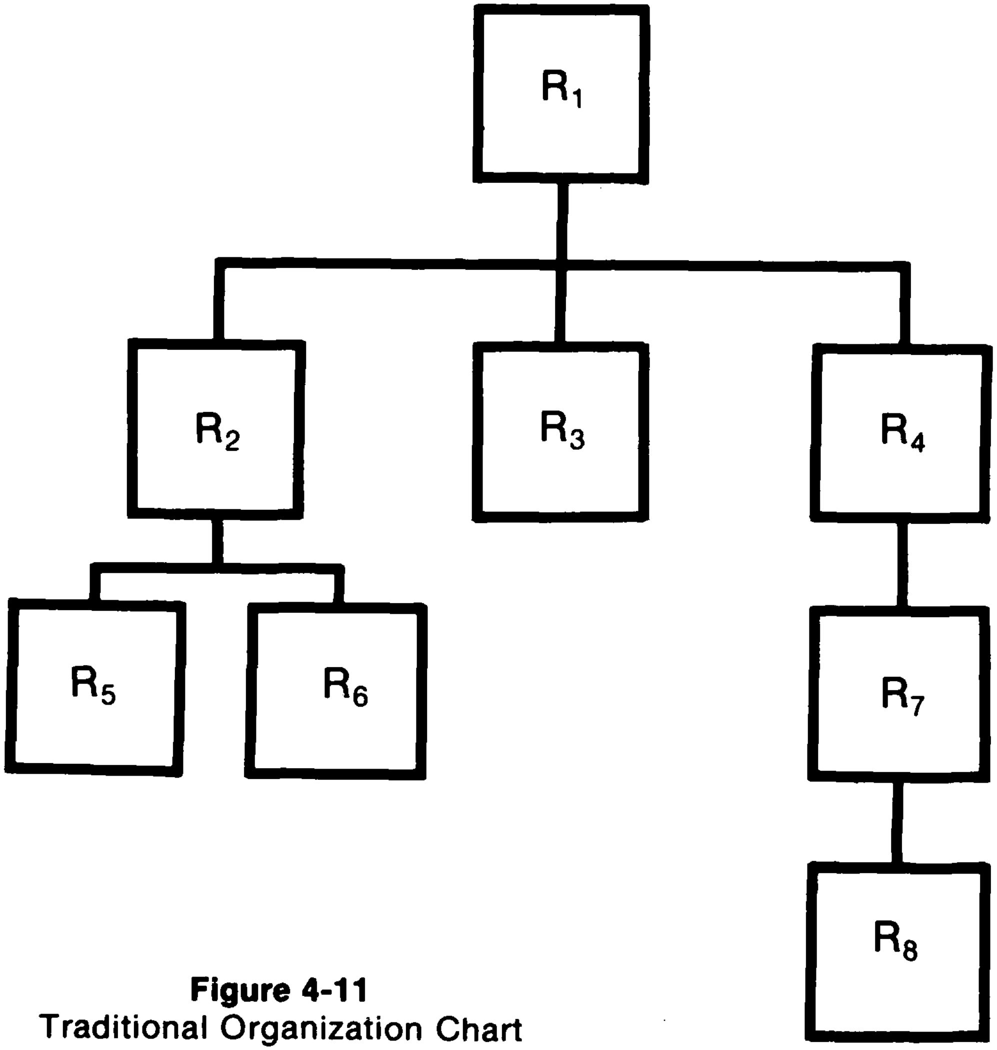


Figure 4-11
Traditional Organization Chart

4.3.2.2. Groupings of Resources

The essence of human organization is that relationship structures are present which promote the synergistic application of resources toward goals, which allow the organization as a whole to be more productive than its elements, the resources, could be, acting alone. We recognize that, in pursuit of this productivity increase, resources are grouped together: in committees, sections, divisions, and work teams in the case of human resources; in factories, office buildings, and shopping malls in the case of space resources; and in production lines, job shops, and chemical processing plants in the case of equipment resources. Mutual funds and money market funds are simply relationship structures which allow grouping of financial resources in hopes of increasing productivity.

Within the context of the model, assignment of any resource to an identified group can be made by marks in appropriate cells of a matrix assigned to the group. Figure 4-12 shows one possible notation, showing members of a single committee, chaired by R_1.

Figure 4-13 shows an alternate notation for pure membership in the group, allowing no authority relationship between any single resource and the committee as a collective resource to be noted.

Figure 4-13 shows a great deal of redundant information which could be eliminated if we introduce the notion of the group or committee itself as a resource, distinct from the original resources R_1. Let the group be resource R_9. Figure 4-14 shows the same membership information as does Figure 4-13.

Generalizing, now, on the concept of resource, we see that any explicitly defined entity (individual) person, team, section, department, division, committee, office, titled position, equipment, space) can be

R_1		X	X		X		X
	R_2						
		R_3					
			R_4				
				R_5			
					R_6		
						R_7	
							R_8

Figure 4-12
Membership in a Committee Chaired by R_1

R_1		X	X		X		X
X	R_2	X	X		X		X
X		R_3	X		X		X
X		X	R_4		X		X
X		X	X	R_5	X		X
					R_6		
X		X	X		X	R_7	X
X		X	X		X		R_8

Figure 4-13
Membership in a Group for which No Internal Authority Relationships are Shown

R_1								X
	R_2							
		R_3						X
			R_4					X
				R_5				
					R_6			X
						R_7		
							R_8	X
								R_9

Figure 4-14
Membership in
Group R_9

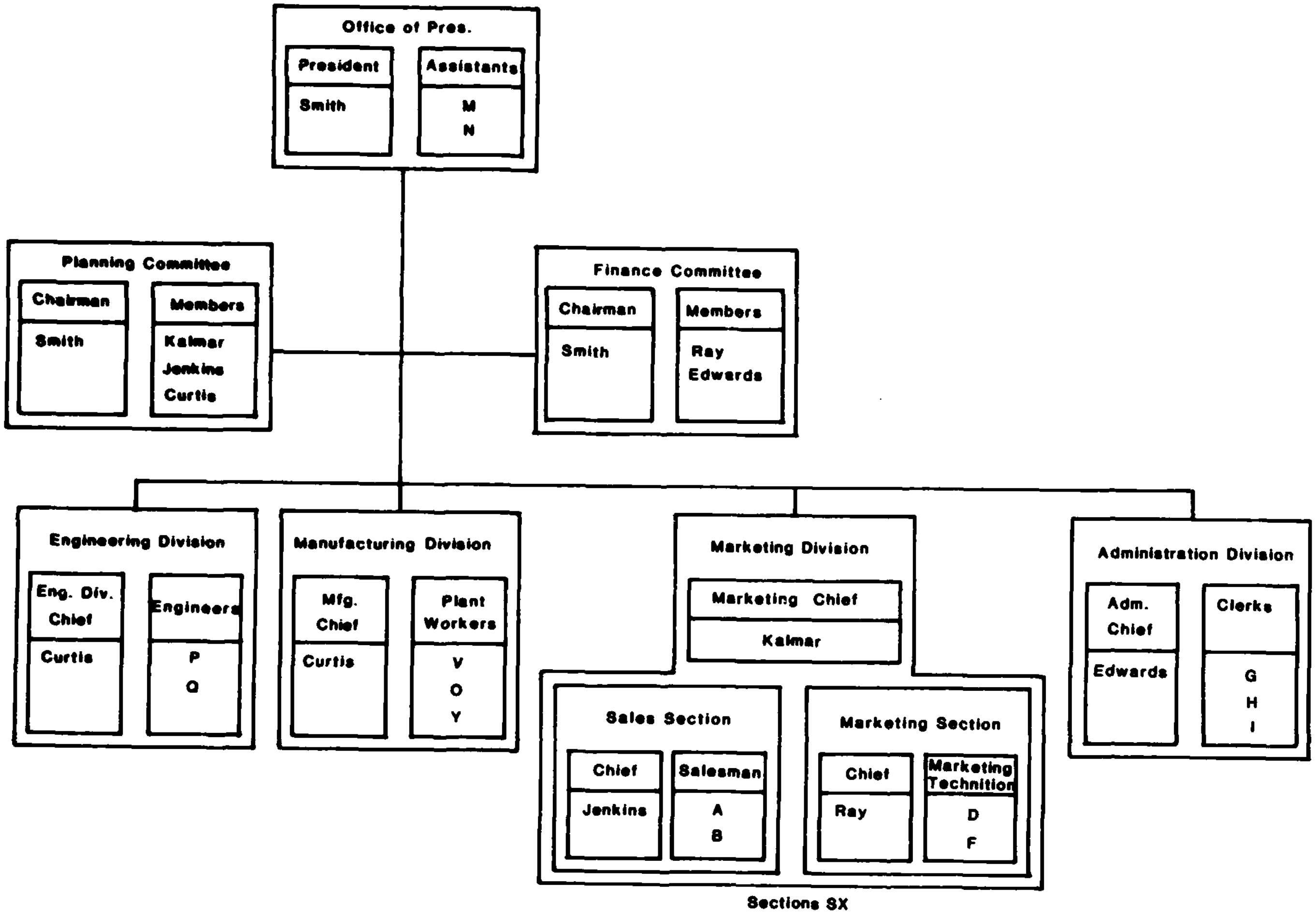
considered a resource which can have diadic relationships with any other resource. Figure 4-15 shows a traditional organization chart for a hierarchically structured organization. Each block represents, not a specific, named, person, but a conceptual resource, a role that, in order for the organization to function, must be filled by real resources, perhaps by humans, perhaps by machines, most often by a mix of human and non-human resources. Only the human resources are focused on in the present discussion.

Figure 4-16 shows the same organization as does Figure 4-15, but only in terms of the highest level of conceptual resources, below that of the single, all-inclusive conceptual resource, the firm itself, termed here OG.

Figure 4-17 shows this same grouping, as it appears in matrix format. Note that this matrix shows membership in a group, namely OG, by all the other resources. It shows nothing about the internal structure of the group OG, however.

Figure 4-18 shows the same organization chart as does Figure 4-16, this time with an additional level of conceptual structure added. Figure 4-19 is the matrix display for this (Figure 4-18) diagram, incorporating and adding to the information in Figure 4-17. From 4-15, we see that the Marketing Division (KD) has two sections, Sales (KS) and Marketing (KM). KS, in turn, contains a section chief (SSC) and salesmen (SM); KM contains a section chief (MSC) and marketing technicians (MT). These group assignments are shown also in Figure 4-19, in matrix format.

We now, in Figure 4-19, have a complete generic description in matrix format of the assignments to groups; we do not yet have specific individuals assigned to any group or position. Neither do we have the authority structure of OG placed in matrix format. We must have both in order to depict even a



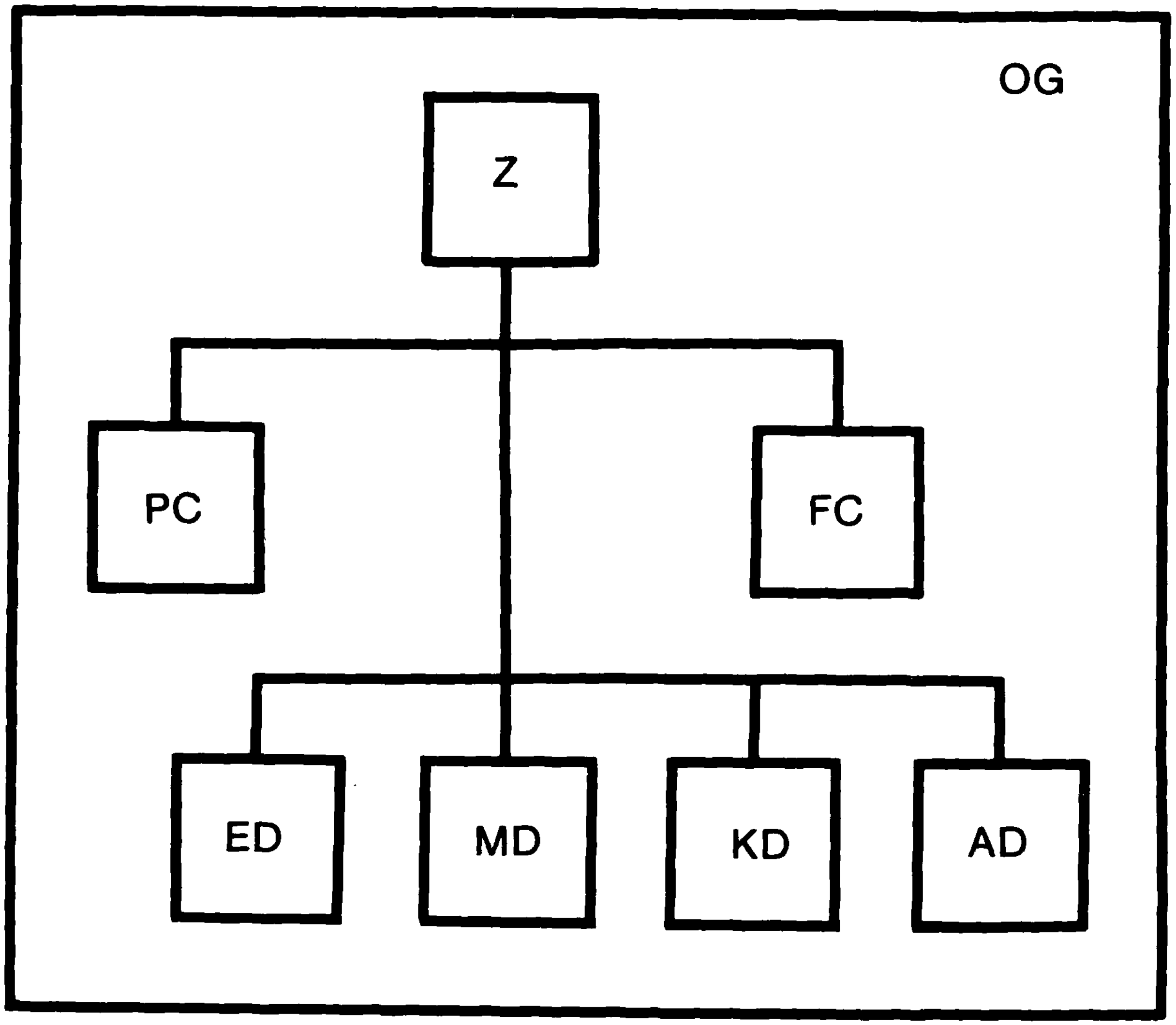
KEY

AD	Administration Division
ADC	AD Chief
C	Curtis
CL	Clerks
E	Edwards
ED	Engineering Division
EDC	ED Chief
EN	Engineers
FC	Finance Committee
FCC	FC Chairman
J	Jenkins
K	Kalmar
KD	Marketing Division
KDC	KD Chief
KM	Marketing Section
KS	Sales Section
L	PC Members
MD	Manufacturing Division
MDC	MD Chief
MSC	KM Chief
MT	Marketing Technitions
PC	Planning Committee
PCC	PC Chairman
PW	Plant Workers
R	Ray
S	Smith
SM	Salesman
SSC	KS Chief
SX	Sections
T	Assistants
U	FC Members
X	President
Z	Office of President

Figure 4-15

Hierarchically Structured Organization of Conceptual Resourses for OG

Figure 4-16
Structure of Highest Level of Conceptual Resources for OG



AD							X
	KD						X
		MD					X
			ED				X
				FC			X
					PC		X
						Z	X
							OG

Figure 4-17
Matrix Representation of Highest Level of Organization of Conceptual Resources for OG

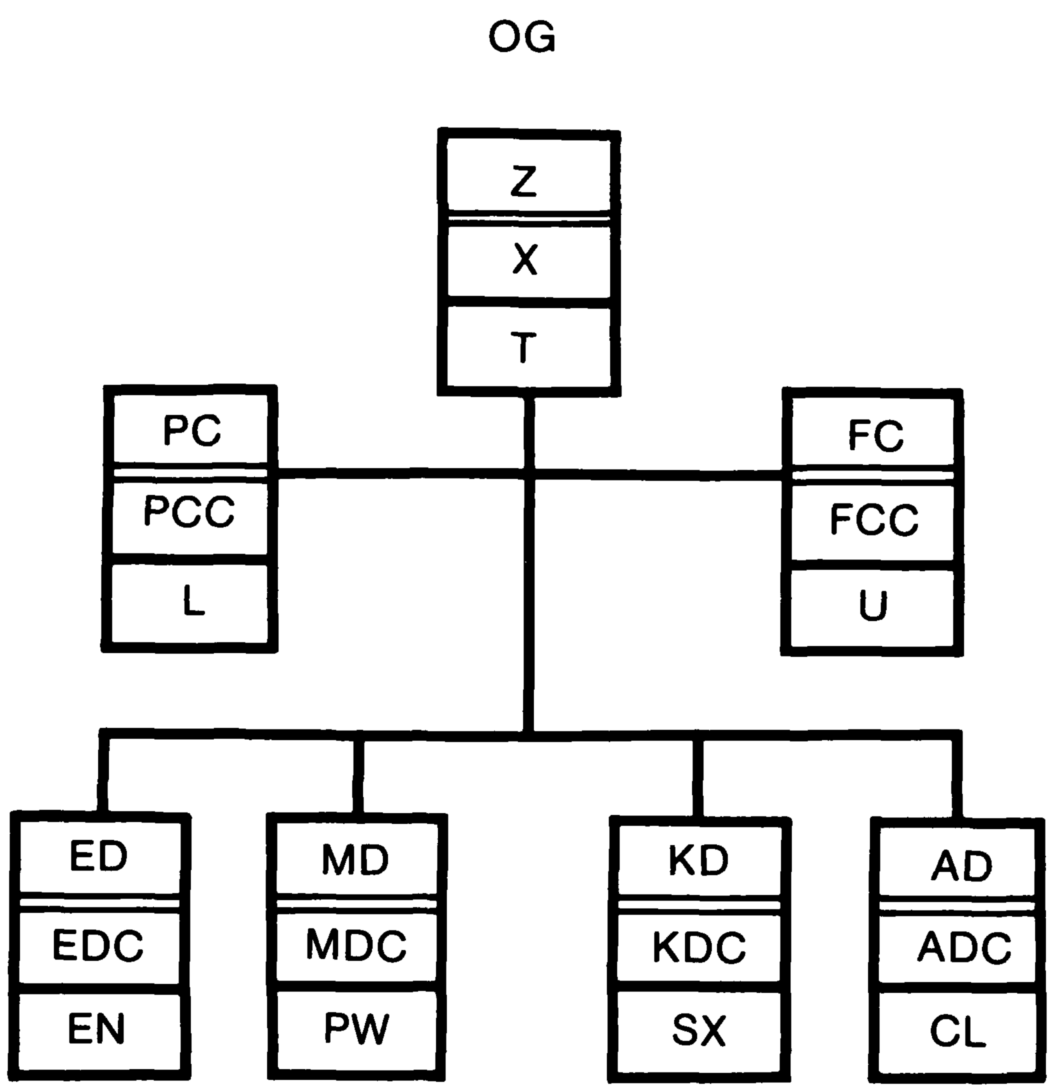


Figure 4-18
Second Level of Conceptual Resource Structure for OG

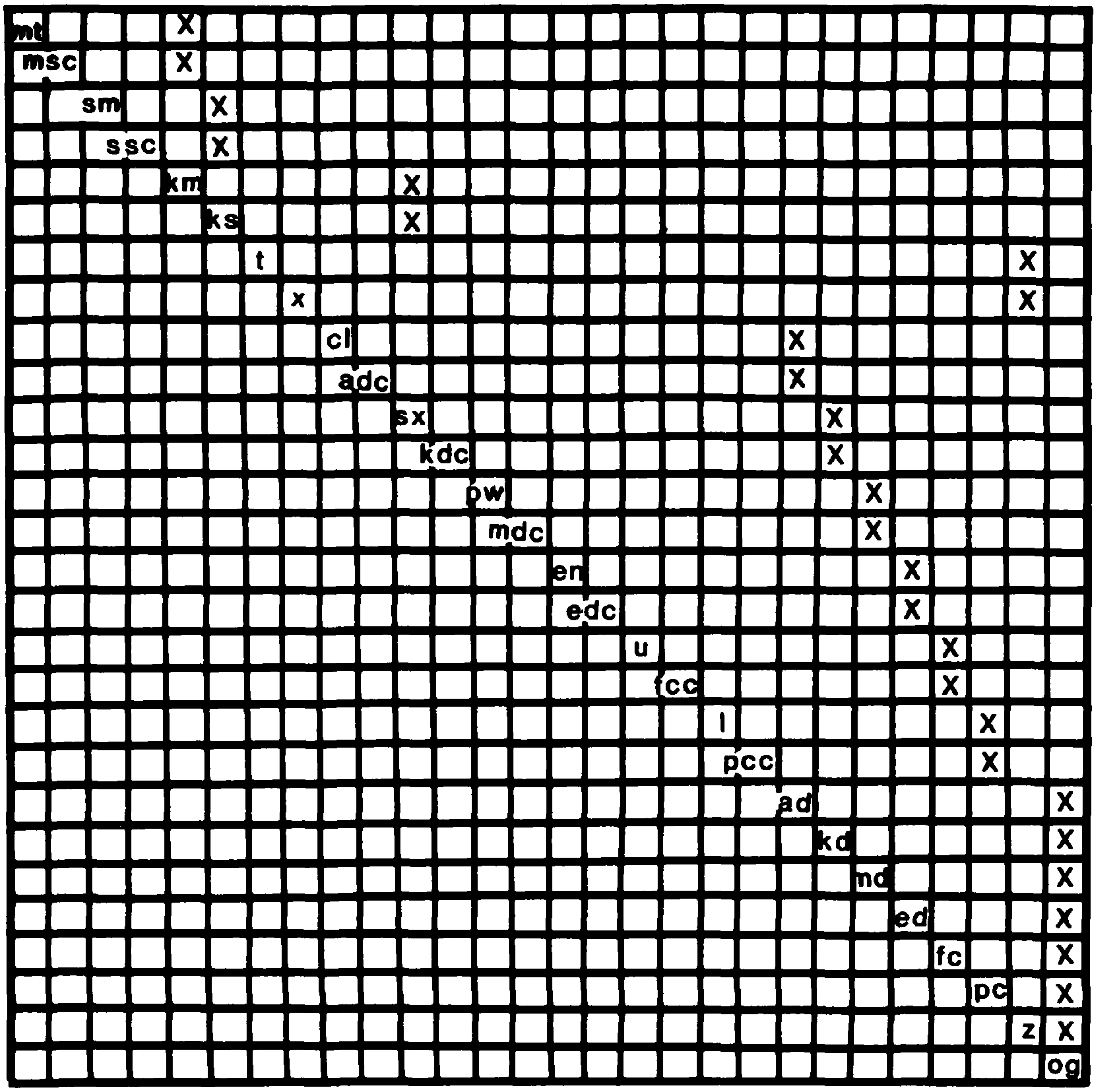

mt
msc
sm
ssc
km
ks
t
x
cl
adc
sx
kdc
pw
mdc
em
edc
u
fcc
l
pcc
ad
kd
md
ed
fc
pc
z
og
X

Figure 4-19

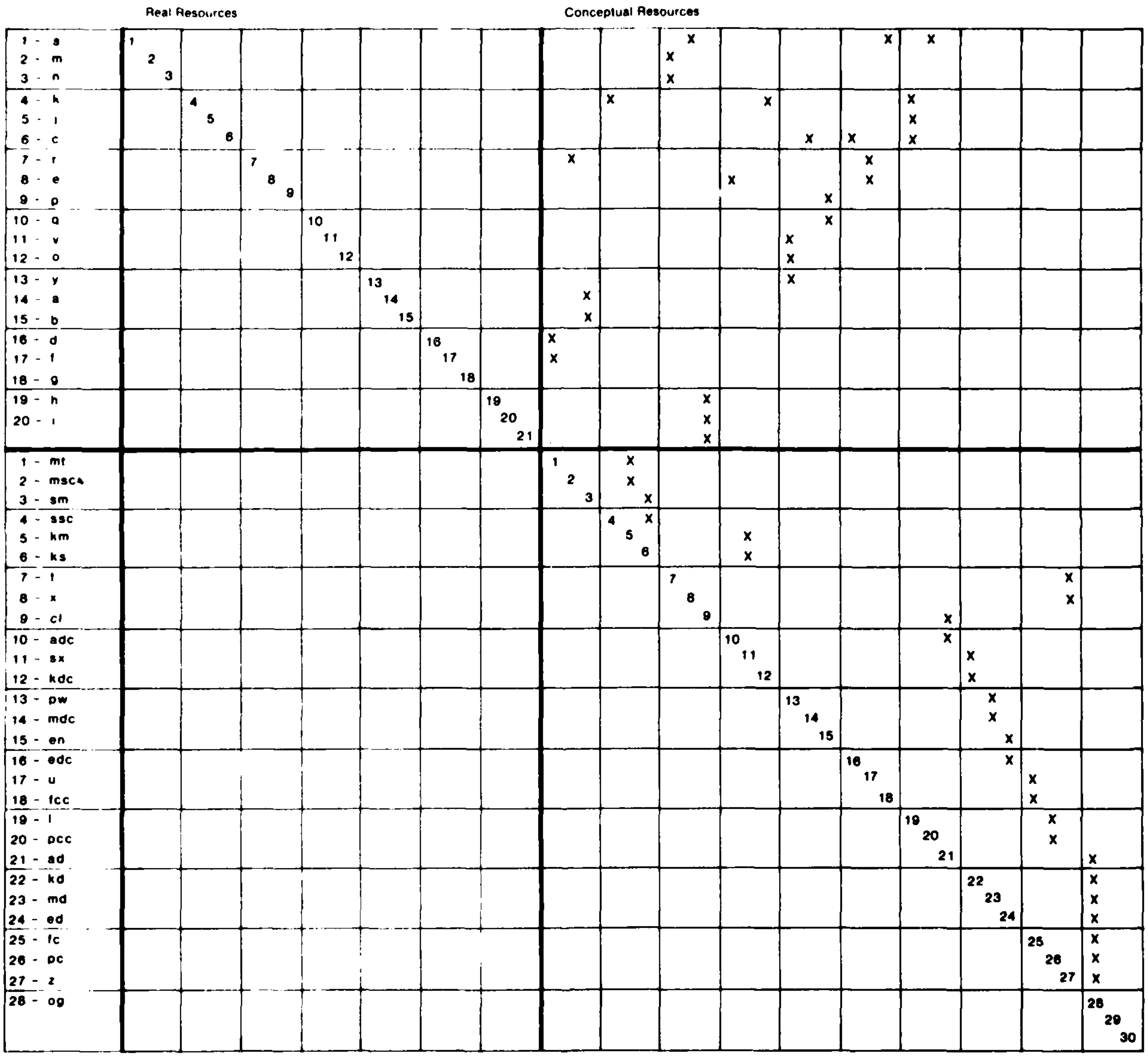


Figure 4-20
Real and Conceptual Resource Assignments

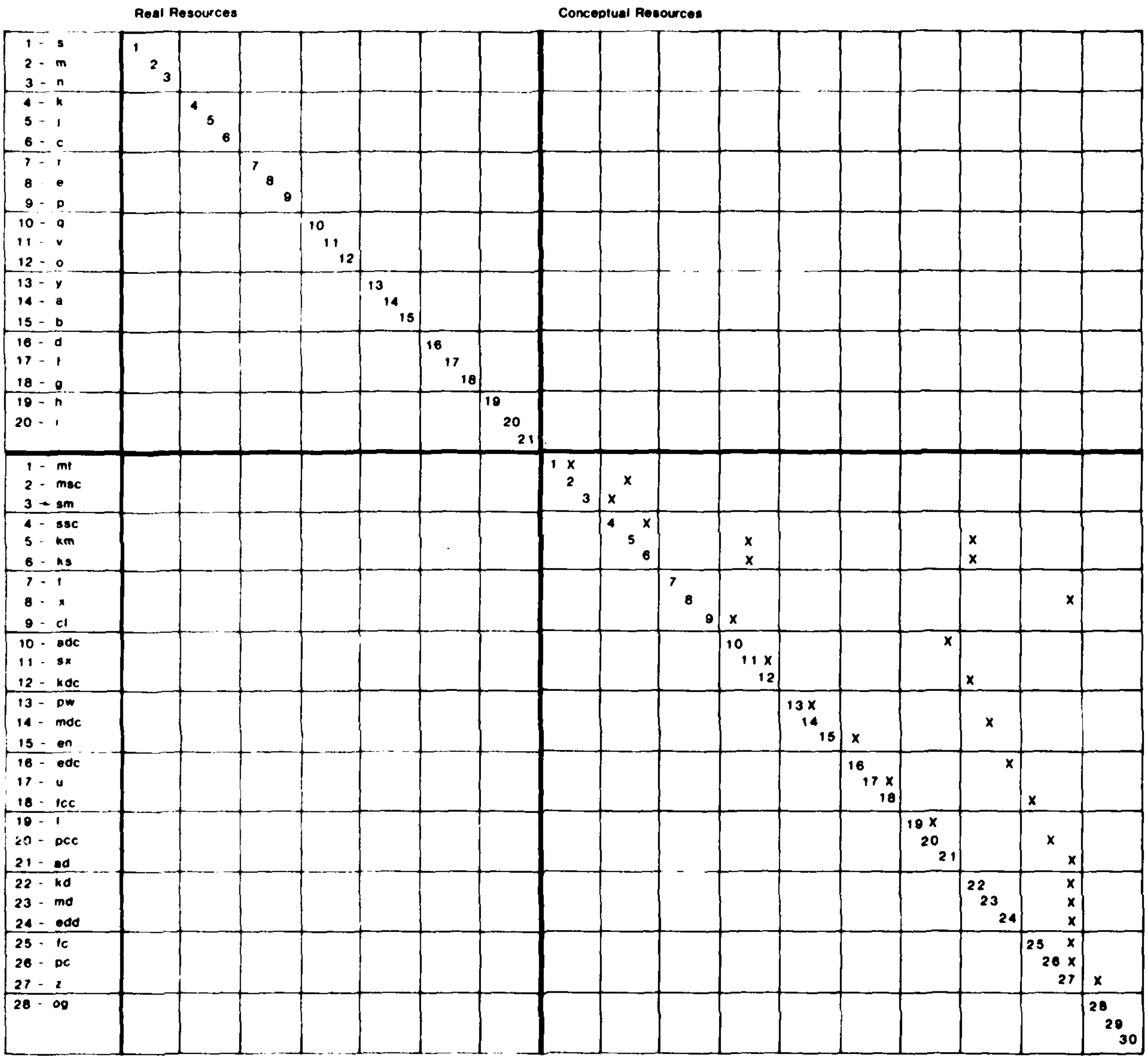


Figure 4-21
Authority Structure of OrganizationZ OG

rudimentary "organization." Figure 4-20 shows individual assignments to positions and groups (roles). Figure 4-21 shows the authority structure of Figure 4-15.

4.3.2.3. Interpersonal Relationships

Examination of Figures 4-20 and 4-21 will show above-diagonal marks indicating the real and conceptual resource assignments and the authority structure of the organization OG. No off-diagonal marks are shown in the sub-matrix corresponding to real resources. This sub-matrix is reserved for notation of inter-relationships between pairs of real resources. In those cases where both members of a diadic relationship are human resources, then notations in this sub-matrix indicate interpersonal relationships which impact on the operation of the organization by affecting the behavior of the individuals (i.e., real resources) in their assigned roles (i.e., conceptual resources). For example, in the case of organization OG, the fact that Jenkins (J) car-pools to work with Company President (X) Smith (S) cannot but influence the performance of Jenkins (J) in his roles as chief of the Sales Section (SSC) of the Marketing Division (KD) and as a member (L) of the Planning Committee (PC), the chairman (PCC) of which is Smith (S). This "car-pools with" interpersonal relationship is surely not lost on the chief (KDC) of the Marketing Division (KD), Kalman (K), to whom Jenkins (J) reports in his role as chief (SSC) of the Sales Section (KS) of the Marketing Division (KD), and potentially affects the interpersonal relationship between K and J, and possibly their performance, respectively, of the KDC and SSC roles.

The entire subject of interpersonal relationships is a complex one having its own structure (ephemeral though it may be in specific situations) of groupings and the informal counterparts to conceptual resources, such as cliques, teams, clubs, special interest groups, and so on, drawing members from exclusively within the formal organization and from society at large (e.g., country clubs, religious, cultural, and fraternal organizations; and familial groups). Surely, the additional intelligence that Jenkins belongs to the same Country Club, Church, and Masonic Lodge as Smith, and is incidentally his brother-in-law is operationally non-trivial to OG. That Jenkins is peeved today at Smith over a $5 loss on a round of golf is of short term importance, but never-the-less an interpersonal relationship which can be handled by the notation. Clearly, the vector of relationships between any pair of real resources is large. While the discussion has dealt with human relationships, the assignment of office space and equipment to specific individuals creates a relationship between animate and inanimate real resources which fall into the present category.

4.3.2.4. "Organization:" Concepts of Structure

A collection of resources, whatever their nature, does not constitute an "organization." The isolated resources must be related to one another in several ways before another entity, the "organization" comes into being with a separate existence from those of the separate resources. While we are not able to categorically state just what new entities must exist as combinations of the basic or elementary ones (like people, machines, rooms), we can intuitively identify some obvious ones. Work groups (sections, teams, divisions, crews), special purpose committees (finance, personnel), and roles (president, secretary, accountant) are all part of everyday business experience. Yet all exist quite apart from the individuals who are members of the groups or play the roles. These abstract entities seem to be the real players in the "game" of organization, and yet none has any manifestation except in certain relationships of basic resources. That is, the Finance Committee, say, does not exist physically. It only exists when real resources, namely persons, are related in such a way as to be members of the Committee. These fictitious resources will be called conceptual resources, and they and the entirety of relationships between pairs of resources, whether real or conceptual, will constitute the conceptual organization. Since relationships change with time, so must the conceptual organization. The unqualified term organization will be used only in a general, intuitive sense, along with firm, company, etc.

In the following, diagonal matrix elements represent, simply, resources, and do not distinguish between real and conceptual resources.

4.3.3. Task-Task Patterns

4.3.3.1. Precedence

Relationships between pairs of tasks (T-T) are noted in the lower right-hand sub-matrix of Figure 4-6. Directional relationships such as time or logical precedence, information or material flows, and inclusiveness are defined as clockwise. That is, if, for example, information flows from a task represented on a higher diagonal element to one on a lower diagonal element are represented by notations above the diagonal; those from a lower element to a higher one, by notations below the diagonal.

4.3.3.2. Independence

Pairs of tasks i and j which have no relationships vis-a-vis each other show empty elements at a_{ij} and a_{ji} at every appropriate level k. Tasks in this category include those whose performance times are independent and those which are not linked by information or material flows.

4.3.3.3. Partially Ordered Sets

There is a large literature on the application of graph theoretic constructs to modeling assemblages of tasks. The field of modern project management is largely founded upon the representation of projects as collections of tasks logically ordered by precedences in a time sequence. If task a must be preceded by task b, then task b cannot be preceded by task a, and therefore cycles or loops cannot exist in a precedence network. Precedence-related tasks, then, may be represented by acyclic, directed graphs. For the present discussion, this is important because acyclic, directed graphs can also be represented in the matrix notation we have adopted here. Figure 4-22 shows an example acyclic, directed graph, which represents a set of precedence-related tasks. Where an arrow goes from point (vertex) i to point j, then, task i must precede task j. Figure 4-23 shows the same information in the now-familiar matrix format. As before, direction is read clockwise in the matrix. Acyclic, directed graphs, as used here, are often called <u>partially ordered sets</u>.

At this point in the development of the model, the factor of <u>time</u> must be considered. While relationships between resources do not involve a time factor, the <u>performance of a task does</u>, and stringing a set of tasks together by precedence relationships clearly implies a passage of time. At this point in the development of the description of the model, it is an advantage to suspend consideration of the time factor and to concentrate on the development of a static model. The extension of the model to a time dimension will be covered in a future report. The next section discusses an important precedent T-T relationship in a static model, that of information flow.

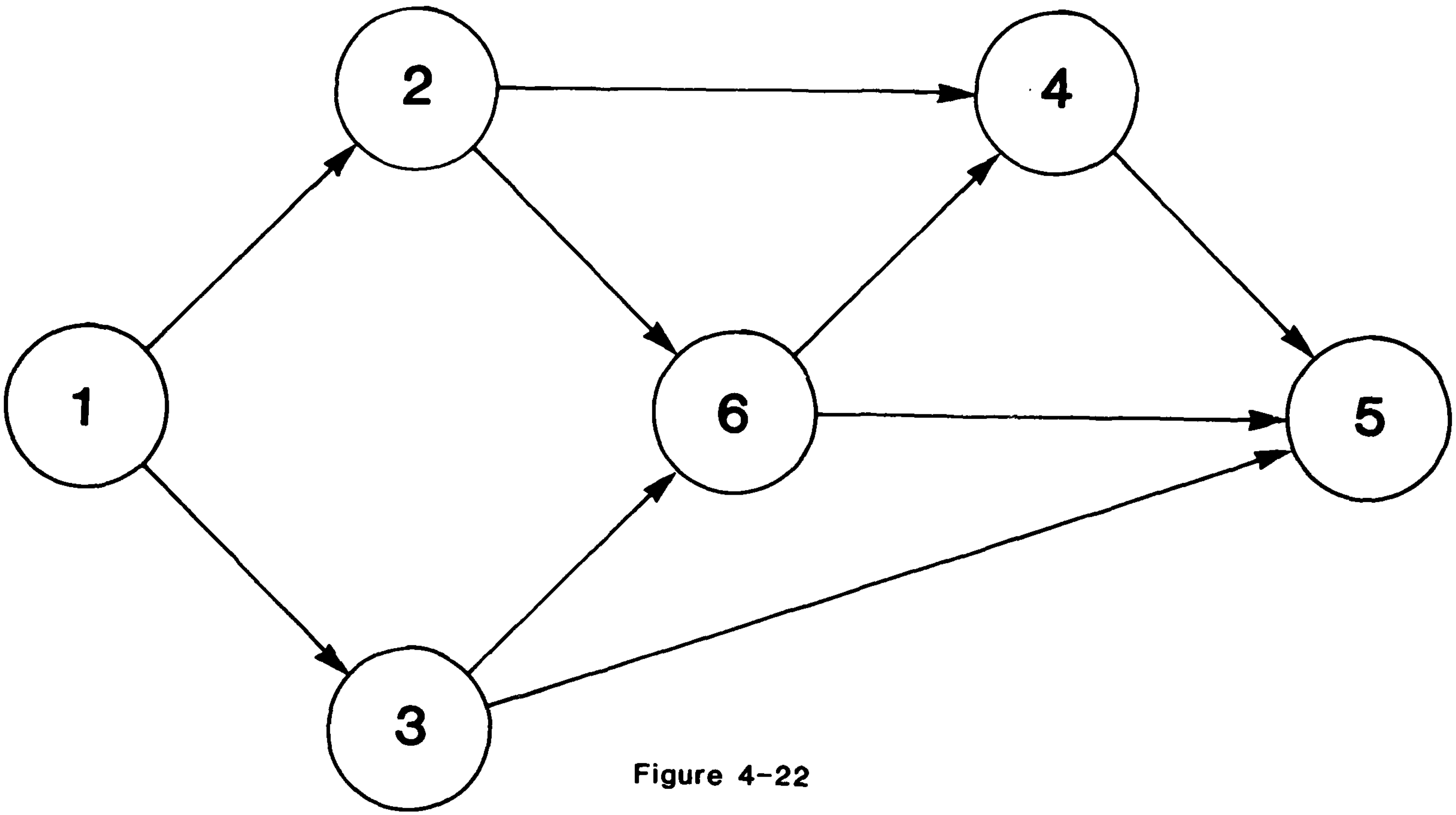


Figure 4-22

Graph Theoretic Representation of Precedence-Related Tasks

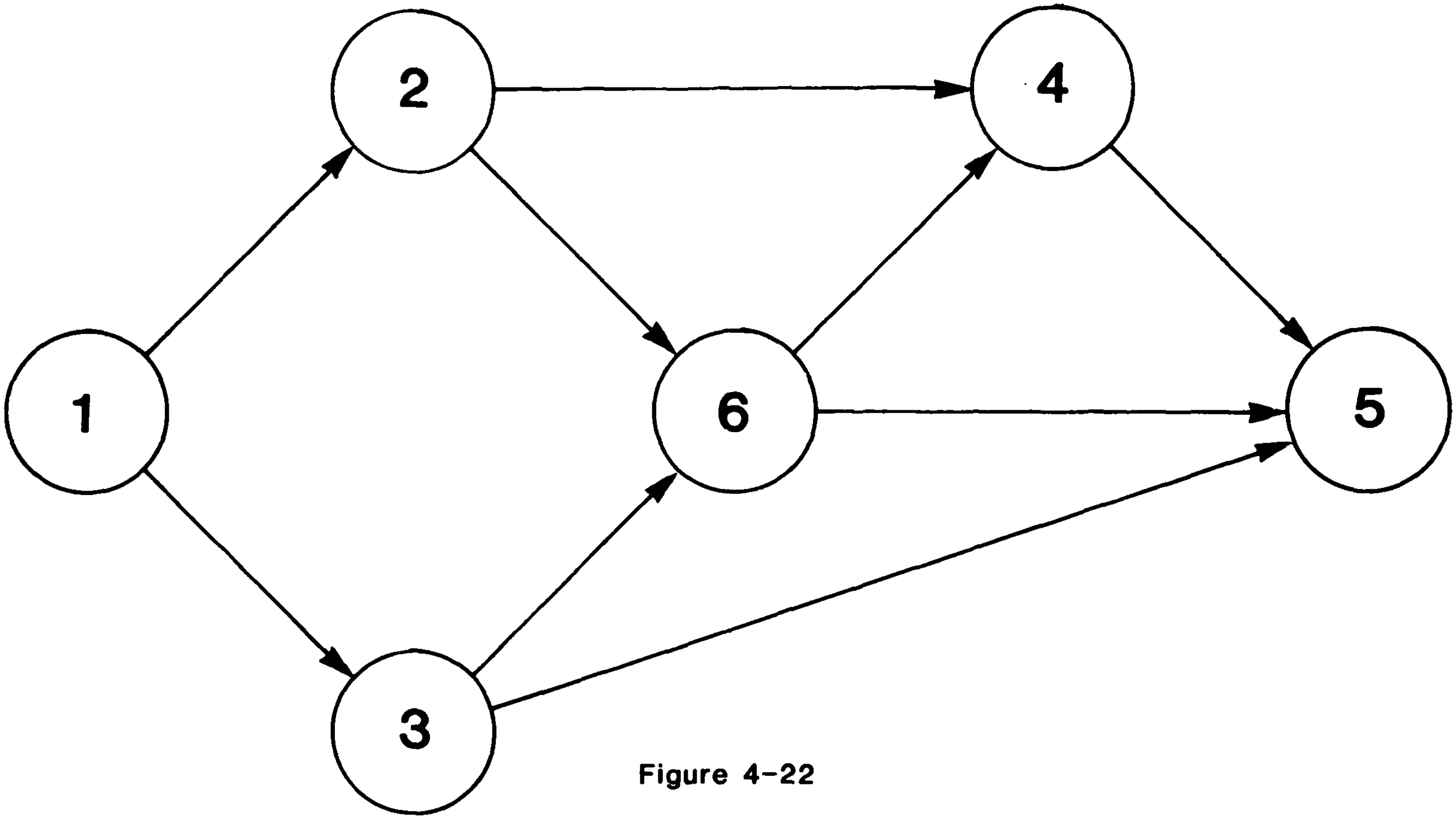


Figure 4-22

Graph Theoretic Representation of Precedence-Related Tasks

1	X	X			
	2		X		X
		3		X	X
			4	X	
				5	
			X	X	6

Figure 4-23

Matrix Representation of

Precedence Related Tasks

4.3.3.4. Information Flow

In the production of any information product, elementary information is assembled into more complex information, which is itself transformed, all through a series of tasks which can be linked together to coincide with the paths the information takes as it is transformed into the final product. If we ignore the factor of time, the resulting directed, acyclic graph, or its matrix representation, represents a map of the process for the assembly of the information product, say, the plans for a building. The tasks, represented by the T-T sub-matrix diagonal elements, are arbitrary in scope and complexity, and present an analog to the structure described earlier for many levels of resources, with both real and conceptual resources depicted on the R-R sub-matrix. This hierarchy of task structure, involving both real tasks and conceptual tasks, is covered in the next section.

4.3.3.5. Task Decomposition

Any task, whatever its level of complexity, can be partitioned into arbitrary sets of simpler tasks. There exists, then, by extension of this notion, a multiplicity of ways that any task can be decomposed into multiple levels of simpler tasks, each level of which is a partition of the level above. We can represent this concept by a tree, which is a special kind of acyclic, directed graph. Figure 4-24 shows a four-level decomposition of a single task. Figure 4-25 represents the same information in matrix format. It is important to note, here, that the meaning of the arrows in Figure 4-24, and that of the X's in Figure 4-25, is "is composed of." This means that, for example, tasks T_4, T_5, and T_6 are components, or partitions, of task T_2, which, together with task T_3, constitutes task T_1.

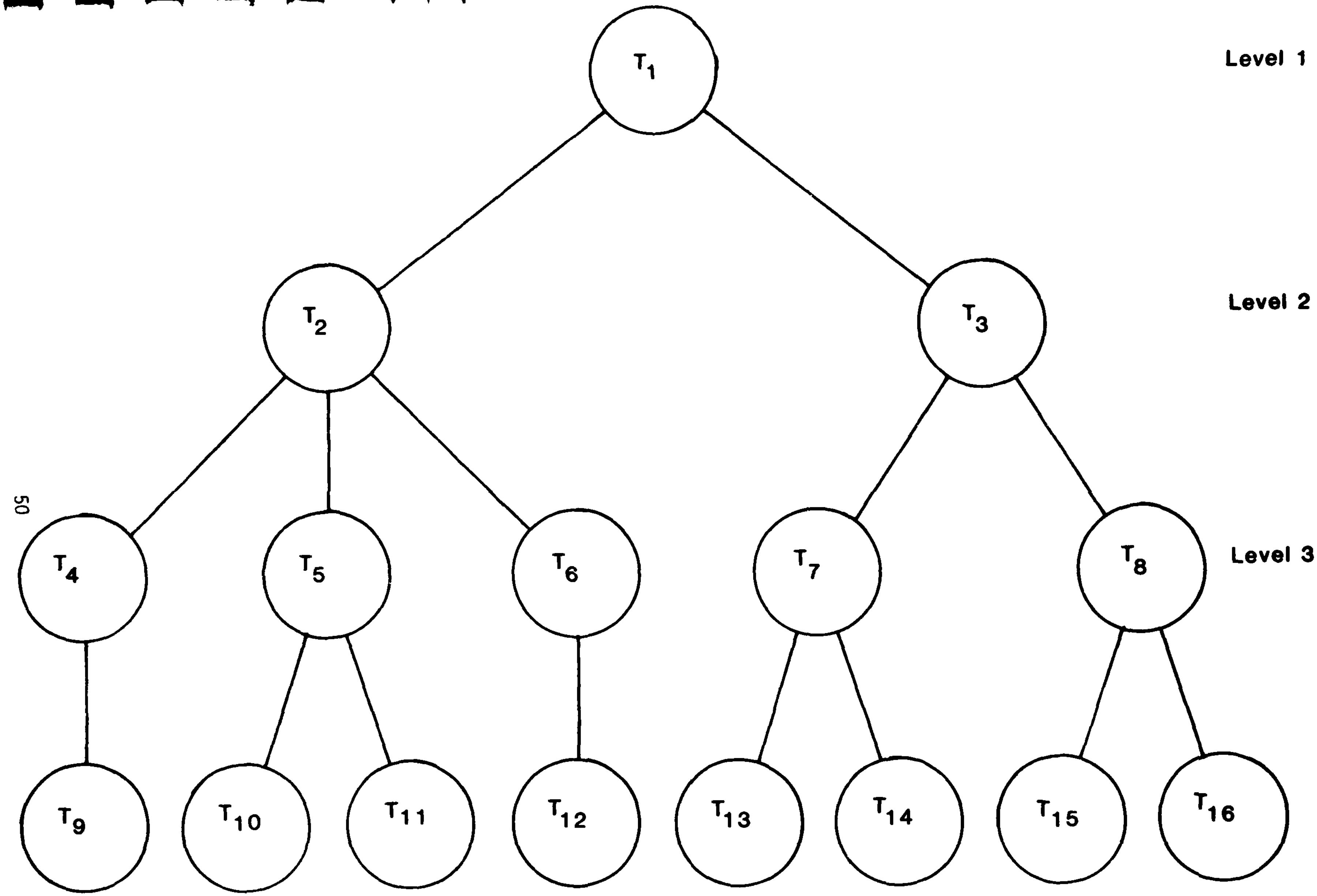


Figure 4-24

Multi-level Decomposition of Task T_1

1	X	X													
	2		X	X	X										
		3				X	X								
			4					X							
				5					X	X					
					6						X				
						7						X	X		
							8							X	X
								9							
									10						
										11					
											12				
												13			
													14		
														15	
															16

Figure 4-25
Representation of Task Decomposition in Matrix Format

We assume, when a task is decomposed into smaller tasks, that the partition is such that there is no "overlap," and that the decomposition is complete, in that the entire super-task is totally represented by the selected set of sub-tasks.

4.3.4. Resource-Task Patterns

4.3.4.1. Relational Categories

At the very lowest level of work management, one worker is assigned one task to accomplish. For 3 workers, here basic resources, and 7 tasks, matrix representation of simple work assignments might appear as in Figure 4-26. The matrix tells us nothing, of course, about R-R relationships, nor about T-T relationships. In keeping with the concept of vector elements, these and all other relationships are noted on separate matrices, one for each relationship.

While in the final analysis the only "real" work is done by a real (basic) resource (e.g., an individual worker) performing a real (unpartitioned) task, the aggregation of the basics, i.e., resources and tasks, into the many conceptual resources and tasks that form the conceptual organization supplies the richness of the machinery of human organization. It is the conceptual organization that gives rise to company jargon, the short hand communication that impels the newcomer and old hand alike to have a shared mental model of the organization and what it does. Conceptual resources allow us to say that "the Engineering Division has almost completed design of the new widget," when in fact we know that "the Engineering Division" has not and cannot do anything - Sam and Joe designed the new widget, in their roles as engineers, assigned to the conceptual resource called Design Group A, itself a part of conceptual

1				X			X		
	2		X		X	X		X	
		3							X
			1						
				2					
					3				
						4			
							5		
								6	
									7

Figure 4-26

Assignment of Basic Resources to Tasks

resource "Engineering Division," and so on. And the marketing of the new widget, assigned to Marketing, will in fact be done by Sally and Frank, the only real resources Marketing has.

But the point is that Resource-Task assignments must be made throughout the entire range of both the task hierarchy and the resource hierarchy if the conceptual organization is to function; and that there are many important R-T relationships other than simply work assignments.

4.3.4.2. Directional Relationships

Continuing with the clockwise directional notation developed earlier, the relations from resources to tasks include such operators as "assigned to," "responsible for," "manages," "directs," and "monitors." These relations appear in the matrix above the diagonal. The inverse relationships, from task to resources, include such feedback operators as "affects," and "provides information to."

As in all relations, the matrix elements here are vectors, capable of containing many distinct R-T and T-R relationships.

5. Experimental Work

5.1. Introduction

The experimental work involved collecting relevant data from an existing organization, converting the data to a useful form and finally determining if the model could accommodate these data. The cooperating firm and the techniques used to collect data are discussed in the following section.

5.2. Cooperating Firm

The target of the investigation is a well-established architectural firm in a middle-sized mid-western city, selected for its size and process layout. The firm employs about 20 people, a number not out of reach of personal interview techniques nor too small to have developed certain explicit organizational procedures. Unlike the typical architectural firm, which has a strong intermittent process orientation, this firm has a large regular client, which tends to give rise to continuous production processes as well as intermittent ones. The firm has the advantage of having a mixture of these process types to be modeled.

5.3. Objectives

The objectives of the experimental work were to establish the applicability of the model to recording organization relationship patterns and to evaluate the effectiveness of the model as a diagnostic and design instrument for purposive organization. First steps were to develop field techniques to identify relational patterns and determine information flow. A second objective was to determine if the actual patterns in the organization could be depicted in the model or if modifications were required to be made to the model.

5.4. Procedures for Data Gathering

5.4.1. Briefings

An initial briefing was held by the research team for the two principals of the cooperating firm. At this meeting, the objectives and plans for the study were explained, and permission was given for each employee to be interviewed individually. Before any of the employees were interviewed, an outline of questions to be asked of each interviewee was prepared. The intent was to minimize ambiguity in the questions and to provide a framework for the interviewees to relate to the project's goals.

5.4.2. Interviews

Each member of the firm was subsequently given a semi-structured interview lasting approximately forty (40) minutes with both research assistants acting as interviewers. Each session started with a brief discussion of the model, to serve as a basis for the interview.

The interviewers' initial move was to ask each worker, "What do you do?" This approach, however, elicited too broad a response, and it was replaced with, "As an employee of this firm, what do you produce?"

Once an interviewee responded to this question by naming a product, it was easy to pinpoint specific responsibilities and projects to ask about. Once several broad levels of responsibility were established, it was possible to get to the level of information required for the model: How were these tasks performed? How did this one individual resource link to other resources in order to accomplish his/her responsibilities (tasks)? How and what kind of information flow took place?

The tactic that proved most successful in eliciting the degree of detail the research required was the use of specific examples. When interviews revealed a level of responsibility important to pursue, but the interviewee was responding in too general a way, he would be asked to outline in detail a specific example. Once he focussed on a specific example, he was asked to verbally outline, chronologically, step by step, the actions and interactions that took place during the example project. Once he outlined what took place during a specific code search, or preparation of a specific set of working drawings, a pattern began to develop as to how he, as one human resource, interacted with other resources to accomplish various tasks.

As a means of getting closer to the information flow taking place between employees (human resources), several additional questions were asked: What does everyone else do? Describe the nature of the contacts you have with each of your fellow employees and employers. Through this approach, varied and often conflicting patterns of the inter-resource activities began to emerge.

A final question that elicited interesting responses came when each interviewee was asked what he thought he was hired to accomplish. Responses provided the opportunity to compare these answers to the actual duties or tasks they had described earlier. It also gave an additional opportunity to cross-reference elicited information, for use in future studies.

5.4.3. Tape Recordings

With the permission of each interviewee, the interviews were taped as a means of providing accurate raw data back-up. An ordinary cassette tape-recorder was used.

5.4.4. Abstraction of Data from Interviews

The abstraction of data from the interviews required understanding terminology, structuring the data and development of a common notation. With every interviewee response, the interviewer examined and questioned the terminology in order to assure understanding as well as cross-interview consistency. Even with this clear interpretation of the response, it was necessary to structure the data in the model from the beginning. Therefore, the data was collected on (1) all tasks done by an individual, and (2) all organizational relationships of that individual with other resources while doing tasks. This last part of the data structure was accomplished knowing that it is not a complete picture of tasks in the larger organizational structure. Using the common terminology and data in a regular structure, a notation was developed. For example, the names of the tasks given to us by an interviewee were converted into an input/output notation.

5.4.5. Computer Storage

5.4.5.1. Equipment

The equipment available for use in this project included a printing terminal (DEC Writer III), connected to a University-wide computer system, a CDC CYBER 175.

5.4.5.2. Technique

This equipment made available to us several techniques, including routine data storage, text editing and cross-referencing of compiled data.

5.4.5.3. Coding of Data and Relationships

As a means of clearly storing these data, a preliminary code system for data and relationships was devised. Tasks were grouped by resource. These tasks were derived from the interview information.

A long range plan is to convert these stored data to a task orientation. Then, using the task-oriented data, routine relationships can be isolated, and redundant terminology can be detected.

5.4.5.4. Format of Listings

One final achievement made possible by the computer storage system is the routine listing capabilities. Minor tasks achieved in order to complete major tasks may be listed. These major/minor task outlines or lists are organized by resource. If reproduced en-mass, organizationally connected, they would produce an organizational tree structure. These data will be used to produce a hierarchical arrangement of tasks in the model's input/output format; the intent is to move toward automation of the transition from raw data to relational matrices in the model's format.

5.5. Data and Its Interpretation

5.5.1. Edited Transcript of Typical Interview

Every individual interviewed was given a brief outline of the project, an explanation for the taping of the discussion and an example of the type of information sought. The following is an abbreviated transcript of such an introduction given to Mark (employee) by Pat (researcher).

Pat: "Mark, we are using this tape as back-up for our own notes. It will never be played for anyone other than our research group. In other words, it will not be heard by your employer or fellow employees.

Our project is aimed at the development of an organizational model. Our model is task oriented, so we are interested in the information flows that occur in your office, the process by which tasks are accomplished. Perhaps it would be helpful for me to mention that we are looking for the type of information that helps us understand how your particular firm really functions. We are not just looking for job titles and formal hierarchical arrangements, but for the subtleties of the operation...."

This and other introductions were followed by examples of the types of information and examples sought.

Pat: "Our model has a firing mechanism. An example would be the introduction of a new job to the firm's work load. In other words, getting a new job fires or initiates a series of tasks and procedures which are accomplished by the assignment of resources (people and space). Any new job you get into the firm requires that resources (people) be assigned to do the work. What is more, there are probably many different ways those jobs are accomplished. Those alternate combinations of people and methods are depicted in our model as alternate procedures."

First questions usually were deliberately posed in broad terms, in order to elicit a response that would indicate whether or not they understood our introduction. For example,

Pat: "Well, Mark, what would you say your goals are with the firm? What is your purpose or function?"

Mark: "Well, my purpose or function is pretty much that of a draftsman. I've had about eight months experience with the firm. My goal is to work until I get enough "board" time to be able to move up to more responsibilities. Hopefully, that would mean the opportunity to put together a whole project. I guess something like being a project manager would be realistic in 3-4 years."

The next question or questions were more specific, with the purpose of eliciting what they, as individuals, expected or how they viewed their responsibilities.

Pat: "Recalling when you were hired, could you describe what you expected your job to be? We recognize that you were hired for drafting but what did that job mean? What did those responsibilities actually become?"

Mark: "In particular, I was hired to work on the Medical Center. The firm had just completed the design for the Center, so I was to be working on the construction documents, with no design drafting. Specifically, I did architectural floor plans, details, and coordination of those drawings with the mechanical engineers and our structural consultant. I also had contact with the contractor. Every so often I had to check and make sure these things were in keeping with the client's intentions."

Pat: "Any other types of jobs you have been assigned to?"

Mark: "Perhaps the most unusual things that I've done since working here was the building survey on the Medical Center that I did two years ago. I was assigned to "check out what existed." That was a great way for the firm to get in on the ground level of a project. I mean by doing the initial programming. The Medical Center had to reuse as much of their existing building as possible but they wanted to evaluate what portions were salvageable and which should be destroyed and replaced with the new addition. After that kind of analysis, their next step would be to hire someone to make a plan to develop the project. Following the development of such a project they will no doubt implement it and I won't be the least surprised if our firm gets at least one or two of the nine buildings to design."

Pat: "OK, Mark, you have drafted and surveyed projects; can you think of any other responsibilities you have had?"

Mark: "When I worked on the Bank, I did some survey work, but that was quite similiar to the Medical Center and I was pulled off of it early to work on something else."

Pat: "When you were pulled off that job, what specifically were you assigned to? Was it a drafting job?"

Mark: "Yes, drafting on another Bank."

Pat: "Have you ever done code searches?"

Mark: "I haven't yet, but if I stay on the Bank job, I expect to. If not on this job, then on a new job."

Pat: "Mark, let's go back to the survey type work you've done. Who specifically assigned you to those projects. Who gave you direction and how? Did you follow an established procedure or "seat of the pants" approach?"

Mark: "The survey of the Medical Center was done over Christmas break. I was hired with one other student, specifically to do that job. We were assigned and directed by John R. who was not a principal at the time. We were working with Greg, another employee who knew more about the overall project and intentions than we did. He knew the firm's procedures, and we didn't. But, on the actual data gathering, Steve and I were pretty much on our own. We were given passes to the building in order to move through as we had to."

Pat: "Where and from whom did you get the passes?"

Mark: "I guess you would say John R. got them through the hospital higher-ups. It was just a label. I don't know what part of the hospital issues those passes. They just identified us as hospital consultants. John R. also worked with the engineer assigned to the project. We didn't."

Pat: "Go on; what exactly did you do after you got those passes?"

Mark: "Steve and I went through one building at a time, floor by floor. In many cases, we went to the sub-zones you don't usually see."

Pat: "How did you know how to proceed?"

Mark: "We just walked through - oh, we had been given a floor chart to follow."

Pat: "What kind of information did you gather? Did you get an outline to follow for the type of information you were to gather?"

Mark: "The first day, we went through a building that was separate from the others. We went through with John and Greg, talking as we did about the things we were looking for. In fact we did that for a couple of days. At that time, John R. asked if we had any questions. Then we split off, he to interview the heads of departments and us to complete the survey of the physical layout. John was getting information about the employees' needs, how they felt about existing space, and what problems there were. We (John, Steve, and I) would get together for lunch every day as well as at the end of the day to discuss what we'd seen. We understood from various administrators that some areas had more trouble than others. Often, John would tell us what to look for in those areas. There was no general outline, just our verbal communication."

Pat: "So, during the survey, you knew what to do, but was there any system? Did John interview department heads before you viewed their physical make-up?"

Mark: "No, we worked simultaneously. John came three days a week, but we were there all five. I don't remember all the details, but it seems that as John wanted information, we got it."

Pat: "Where did you collate the information?"

Mark: "We were given a desk at the physical plant and we made arrangements to meet there at the beginning and end of the day as well as at lunch."

Pat: "After you collected this information and went through a series of coordinating meetings, what happened then?"

Mark: "Well, we didn't get through all of it. I think that what we ended up doing was going through the building quickly. I guess we got through the buildings OK but we didn't summarize the forms. So we agreed to come back to the office here and collate all of the information and if we had any questions to ask Greg to go back to the Center and take some photographs to verify our questions. I guess you would say that at that point all of the information was handed to Greg or John and they took it from there."

Pat: "You really don't know how it was all wrapped together then. Your part was done?"

Mark: "I did see the final package, but by February I was back in school."

The final and most productive step in the interview process is demonstrated by the following example. By asking the interviewee to verbally detail a specific work experience, step by step, the team came closest to the level of detail the research required, and began to understand better the routine lines of information flow.

Pat: "Perhaps, now that we have covered one of the types of work you have done, we can focus on another. How about the drafting responsibilities. Could you take one job that you drafted on and detail your experience step by step. For example, who did you get the job from? What process did you follow after you got the job assigned to you. What did you do first, second, etc.? Who did you have contact with along the way and how often did you have those contacts?"

Mark: "The easiest one I can think of would be the Medical Center, because it was recent. When I started, the first thing that I was given to review was the project manual. I was also given a copy of the schematic design and CDB (Capital Development Board) rules to review on the project. I was told to familiarize myself with the project through these documents. They had just completed the demolition of one building and they suggested that I go up to Chicago and wander through the existing building, which I did. It helped a lot to familiarize myself with just what it was I was dealing with. After two days of familiarizing myself with this information, I began to draw. I had never worked with reproductive drafting before, so I had to get an introduction to that."

Pat: "Who gave it to you?"

Mark: "It was a combined session with John and Tom. As I drew, Tom did most of the approval or disapproval of my drawings. Occasionally I would get feedback from John R. It was about one week of familiarization with the firm and how it worked. Most of the drawings were of the reproductive type so I could pick up right where the design development people left off. That was a new experience that had to be gotten used to, since I had been accustomed to just starting with an overlay of an existing drawing and re-doing it that way, rather than drawing right on an existing print. It was a case now of learning which sheet to draw on when. For a while I kept getting confused, but it becomes routine after a while. It all depends on the size of the building, what kind of technique we use. This project had a lot of complexity to it, so the fewer repeats, the better. Most of the real complexities were handled or drawn by Tom. When we were at about the 50% submission level of the drawings, the engineer came in with his estimates. And by the end of design development, it was suggested that we review the requirements of the project because we were starting to go over budget. The estimates were coming in way too high. As the financial analysis became more detailed and we knew more of what we were doing, we started to get some programatic increases. With these changes, the scope of the project was really exceeding the budget, so we had to re-evaluate what we were going to do about that. In fact, because of these difficulties, the project got shelved for a while. Basically, that was John's decision. I really had very little to do with any decision making because I was the least familiar with the project. The people like John and Tom would have had more to say about the shelving."

Pat: "Did you eventually get back to that project?"

Mark: "Yes, I did, but I forgot what project I went to in between."

Pat: "Why don't you pick up your description with when you were reassigned to the Medical Center project. Who let you know to start up on the project again?"

This interview went on as did the others, in order to obtain approximately the same level of detail. It was concluded that the specific example technique was the most successful. That is, rather than asking an interviewee to describe, generically, the kinds of tasks he performs, asking for a step-by-step "walk through" his actual role in a specific project produced not only tasks performed, but a logical linking of tasks, defining an information flow. Later interviews showed greater application of it and a proportional reduction in questions of a more general nature.

5.5.2. Interpretation of the Data

Before the data taken in the form of taped interviews could be transformed into a form directly applicable to the matrix format, the interview transcripts had to be read and certain facts extracted. First, a list was prepared of the interviewee's tasks. This required an understanding of the technical jargon of the industry, in this case, the practice of architecture. This was possible because of the technical background of the interviewers and data analysts. The next step required that each task be linked to others by listing, for each task, the required input and its sources and the output and its destinations. The matrix format allows the identification of tasks and the pairing of flow-related tasks, but it does not allow the direct identification of the content of the flows. The implications of this limitation must be examined in a future study.

The results of the interpretation of the data and its presentation in the matrix format appear in the next chapter.

6. Results

6.1. Introduction

The interview technique described in Chapter 5 provided an enormous amount of data about the relationships existing in the study firm. Much of the data could not be accommodated by the basic model presented in Chapter 4, and forced a reconsideration of the structural model. This, in turn, led to the reformulation of the model in the expanded matrix form presented in Chapter 4. With this new framework, the task of portraying the relationship patterns became feasible. This chapter presents representative pattern groups discussed in the study firm.

6.2. Organization Charts

The traditional organization chart is widely understood and seems to be a good starting point for presenting relationship patterns detected in the study firm. Figure 6-1 shows the general organizational hierarchy in block form. Figure 6-1A shows the individuals by name that are assigned to the roles or conceptual resources, again in the traditional format.

Figures 6-2 and 6-2A show in two levels of detail the matrix-management arrangement which the firm uses to manage their resources for project accomplishment. Figures 6-3 and 6-3A show the relationships between human resources and projects.

General Organizational Hierarchy

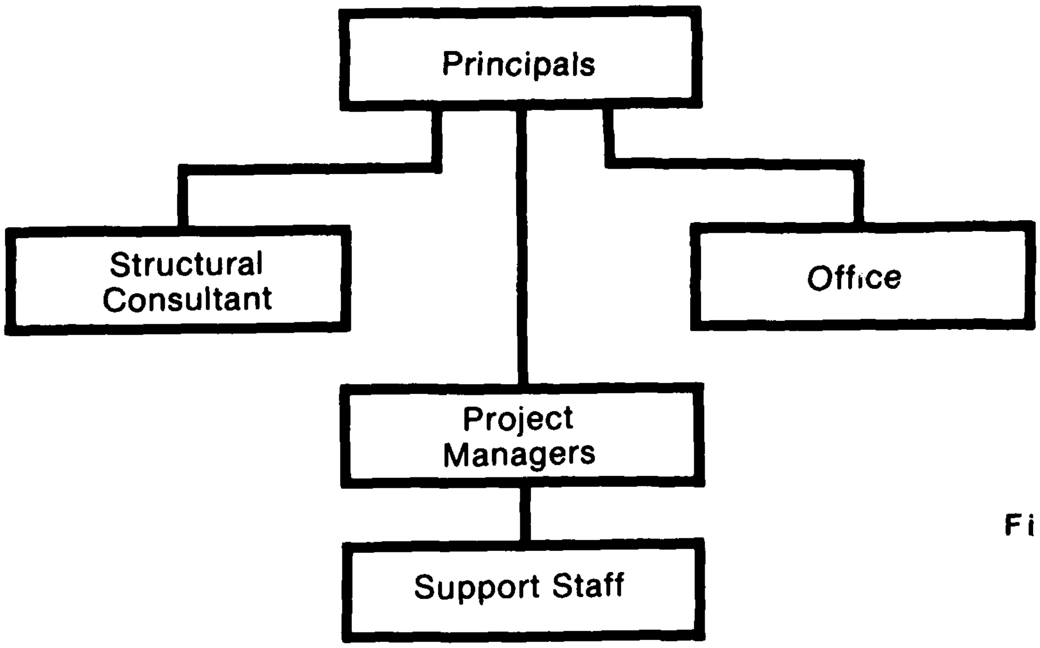


Figure 6-1

Example Organizational Hierarchy

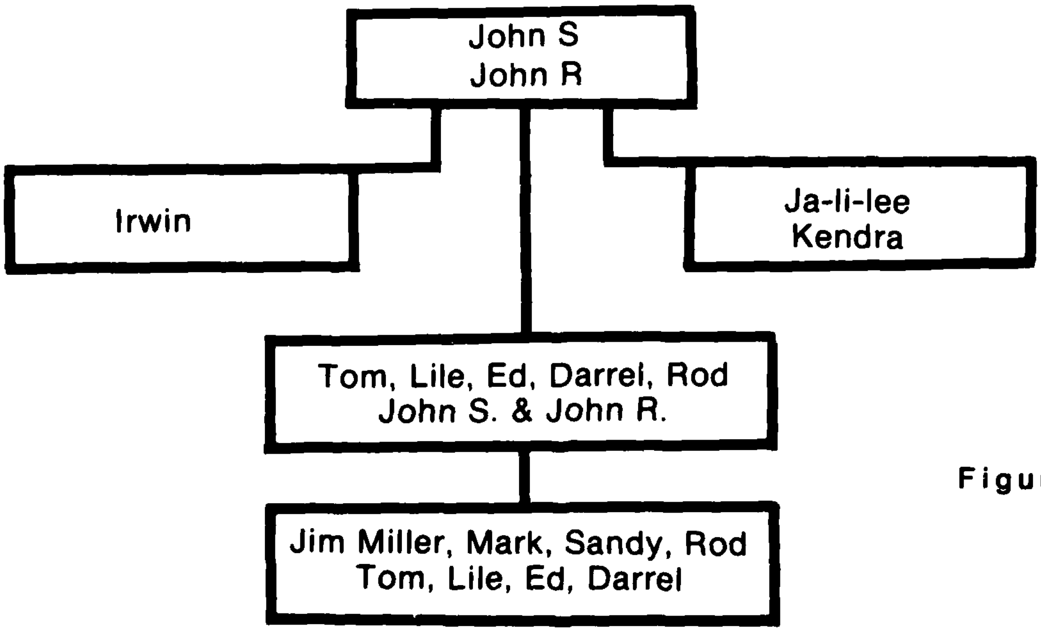
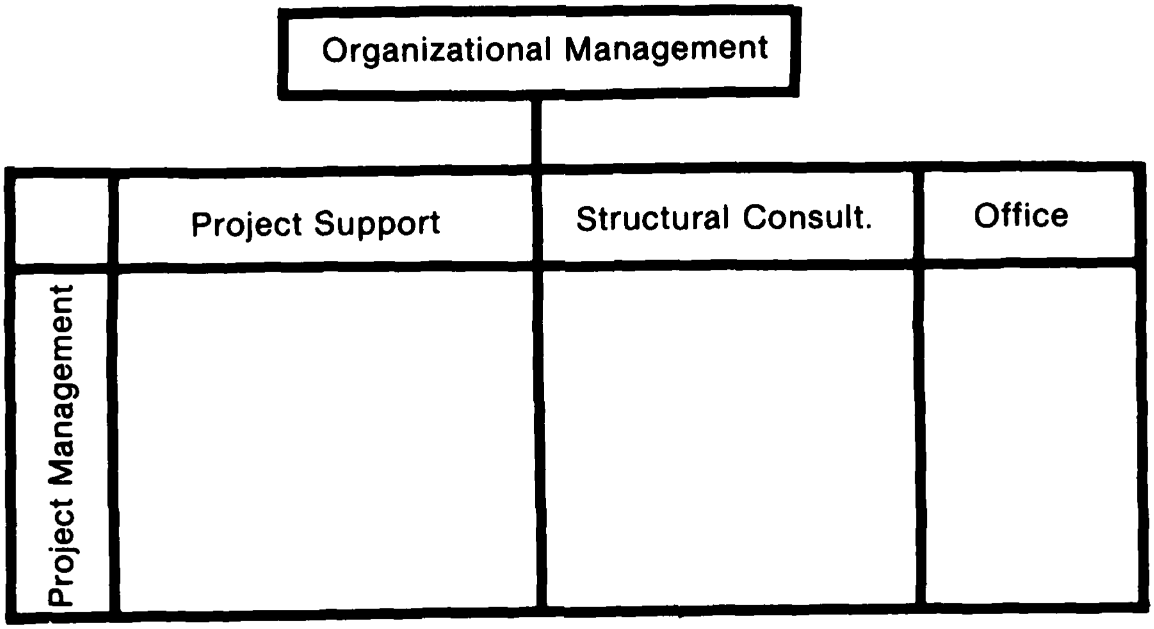
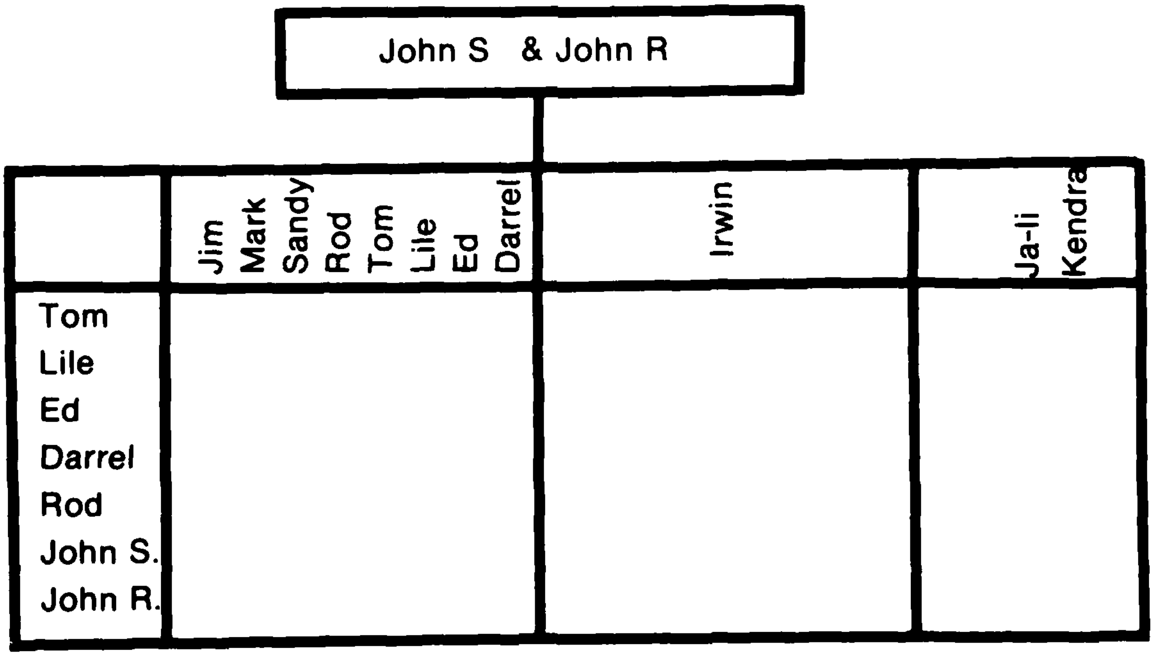


Figure 6-1A



General Management Support Matrix Figure 6-2



Specific Management Support Matrix Figure 6-2A

	Project Management	Support	Structures	Office
Project A				
Project B				
Project C				
Project D				

General Human Resource Task Assignment Matrix Figure 6-3

	John R. John S. Rod Darrel Ed Lile Tom	Jim Mark Sandy Rod Tom Lile Ed Darrel	Irwin	Ja-li Kendra
Bank				
Planning				
IMPE				
Krannert				

Human Resource Task Assignment Matrix Figure 6-3A

These figures present information in traditional formats and are meant, first, to acquaint the reader with the organization in familiar notation; and, second, to show that the format does not lead to useful mechanisms.

In Figure 6-4 is shown a graph-theoretic representation of the conceptual and real resources and the structure of the conceptual resources, in terms of roles and group assignments. In Figure 6-5, the real resources, identified by number at the right side of the figure, are assigned to roles and conceptual resources, by the dashed lines. Note that in several cases, real resources (people) have been assigned to multiple roles and conceptual resources.

It is clear from this figure that the limits of this kind of diagram do not allow one to go much beyond this point. In other words, it is too busy to be useful.

6.3 Matrix Representation

6.3.1. Resource-Resource Relationships

Resource-Resource (R-R) relationships in the study firm, in the matrix representation developed in Chapter 4, are shown in Figures 6-6 through 6-9.

Figure 6-6 shows role assignments of real resources (members of the firm) to conceptual resources (draftsmen, team leaders, secretaries, etc.). Figure 6-7 shows the authority structures within the groups that comprise the conceptual resources. Figure 6-8 shows membership by the roles to conceptual resources which are groups. Figure 6-9 shows membership in higher levels of conceptual resources, all the way up to the highest level, "The Firm."

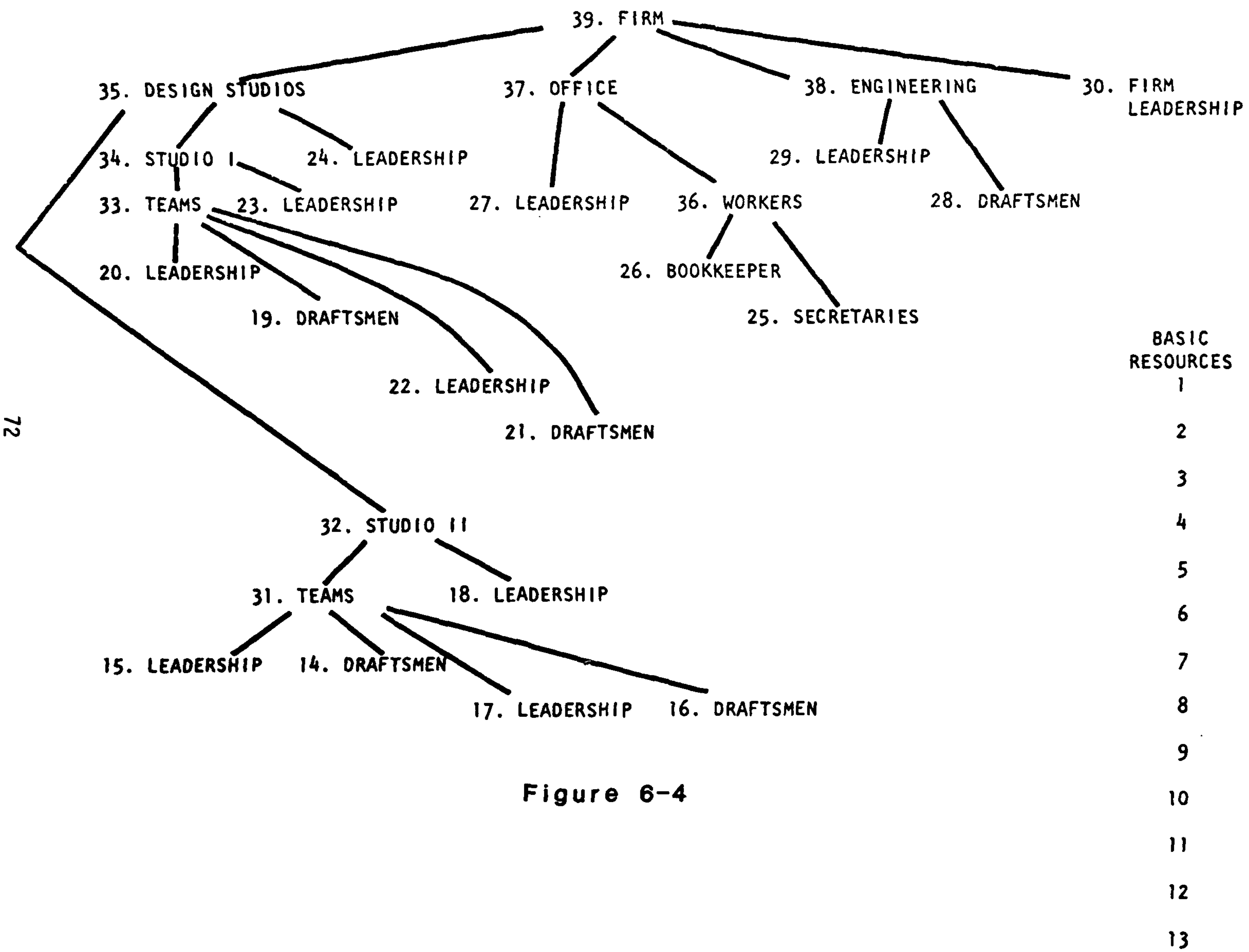

39. FIRM
35. DESIGN STUDIOS
37. OFFICE
38. ENGINEERING
30. FIRM LEADERSHIP
34. STUDIO I
24. LEADERSHIP
29. LEADERSHIP
33. TEAMS
23. LEADERSHIP
27. LEADERSHIP
36. WORKERS
28. DRAFTSMEN
20. LEADERSHIP
26. BOOKKEEPER
19. DRAFTSMEN
25. SECRETARIES
22. LEADERSHIP
21. DRAFTSMEN
32. STUDIO II
31. TEAMS
18. LEADERSHIP
15. LEADERSHIP
14. DRAFTSMEN
17. LEADERSHIP
16. DRAFTSMEN
BASIC RESOURCES
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 6-4

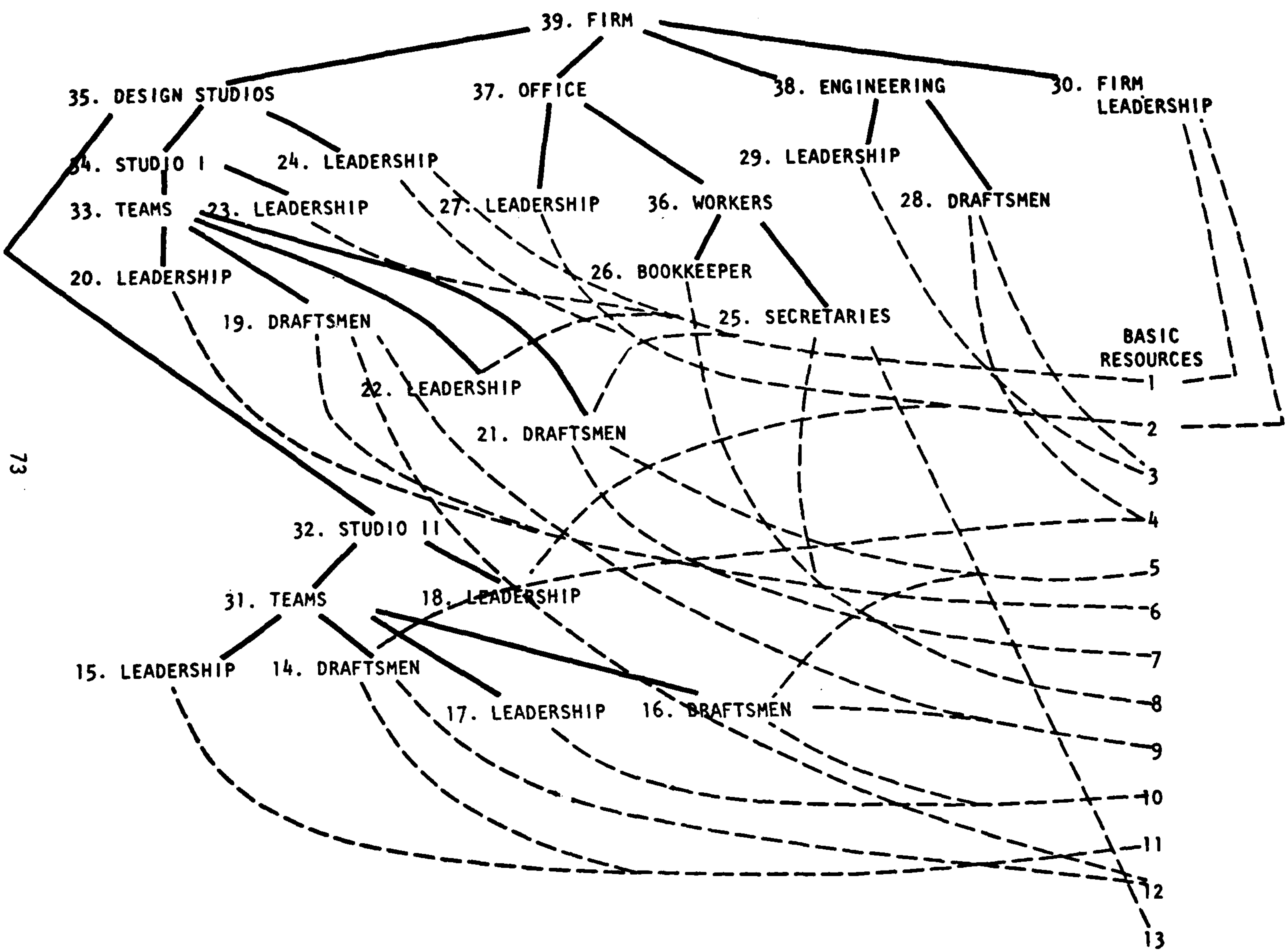

39. FIRM
35. DESIGN STUDIOS
37. OFFICE
38. ENGINEERING
30. FIRM LEADERSHIP
34. STUDIO I
24. LEADERSHIP
29. LEADERSHIP
33. TEAMS
23. LEADERSHIP
27. LEADERSHIP
36. WORKERS
28. DRAFTSMEN
20. LEADERSHIP
26. BOOKKEEPER
19. DRAFTSMEN
25. SECRETARIES
BASIC RESOURCES
22. LEADERSHIP
21. DRAFTSMEN
32. STUDIO II
31. TEAMS
18. LEADERSHIP
15. LEADERSHIP
14. DRAFTSMEN
17. LEADERSHIP
16. DRAFTSMEN
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 6-5

ORGANIZATION OF STUDY FIRM: ROLE ASSIGNMENT

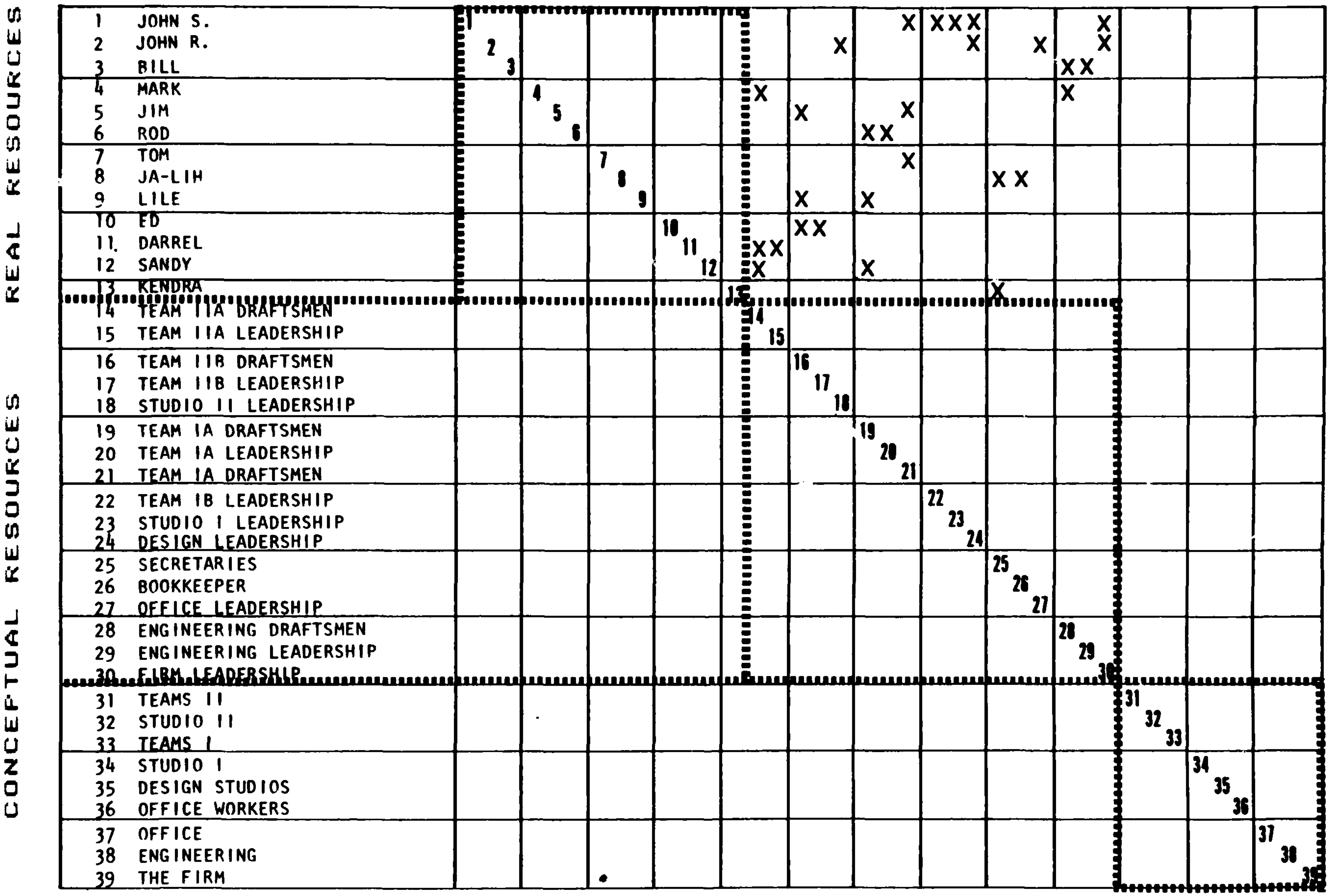


Figure 6-6

ORGANIZATION OF STUDY FIRM: AUTHORITY

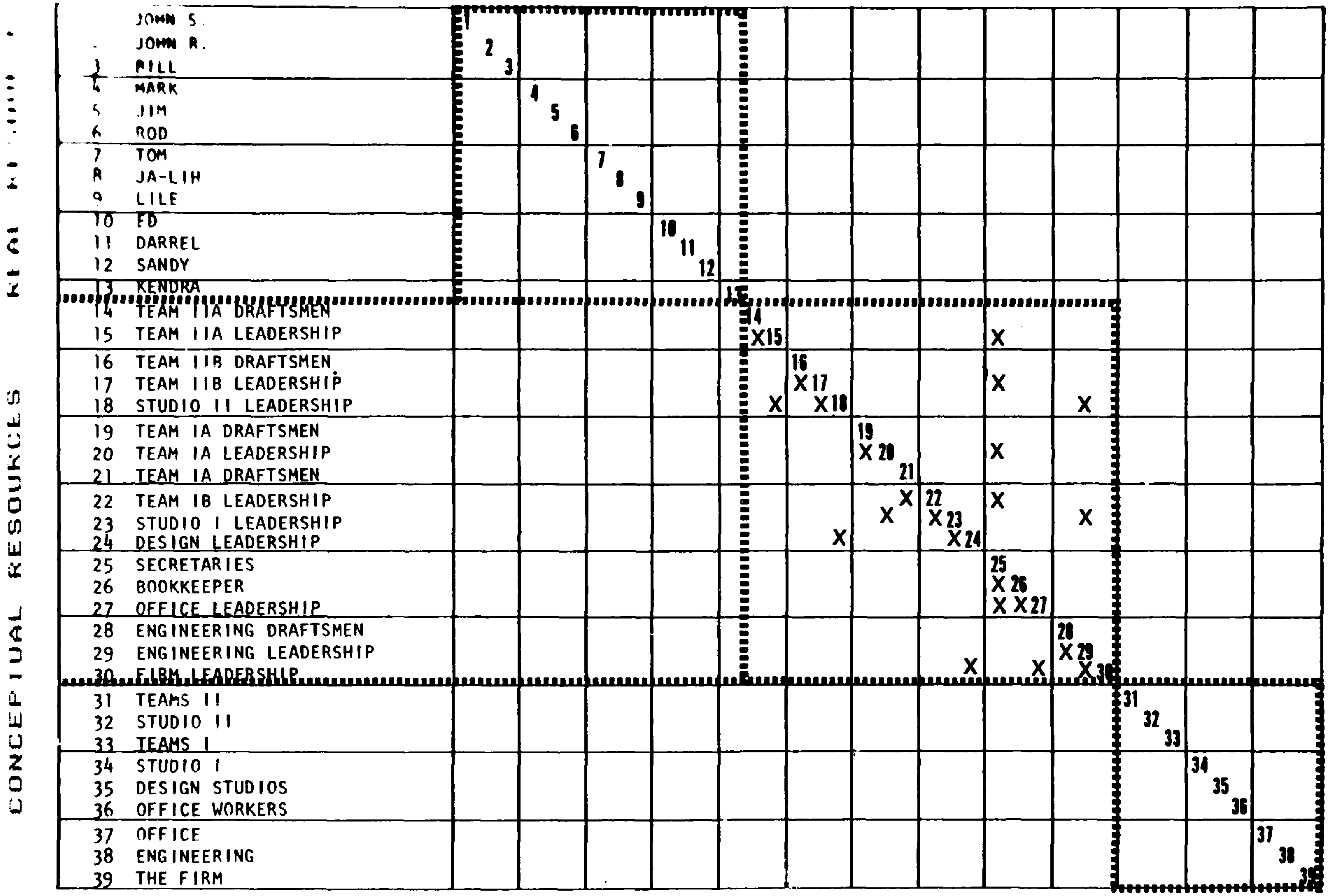


Figure 6-7

ORGANIZATION OF STUDY FIRM: GROUP MEMBERSHIP

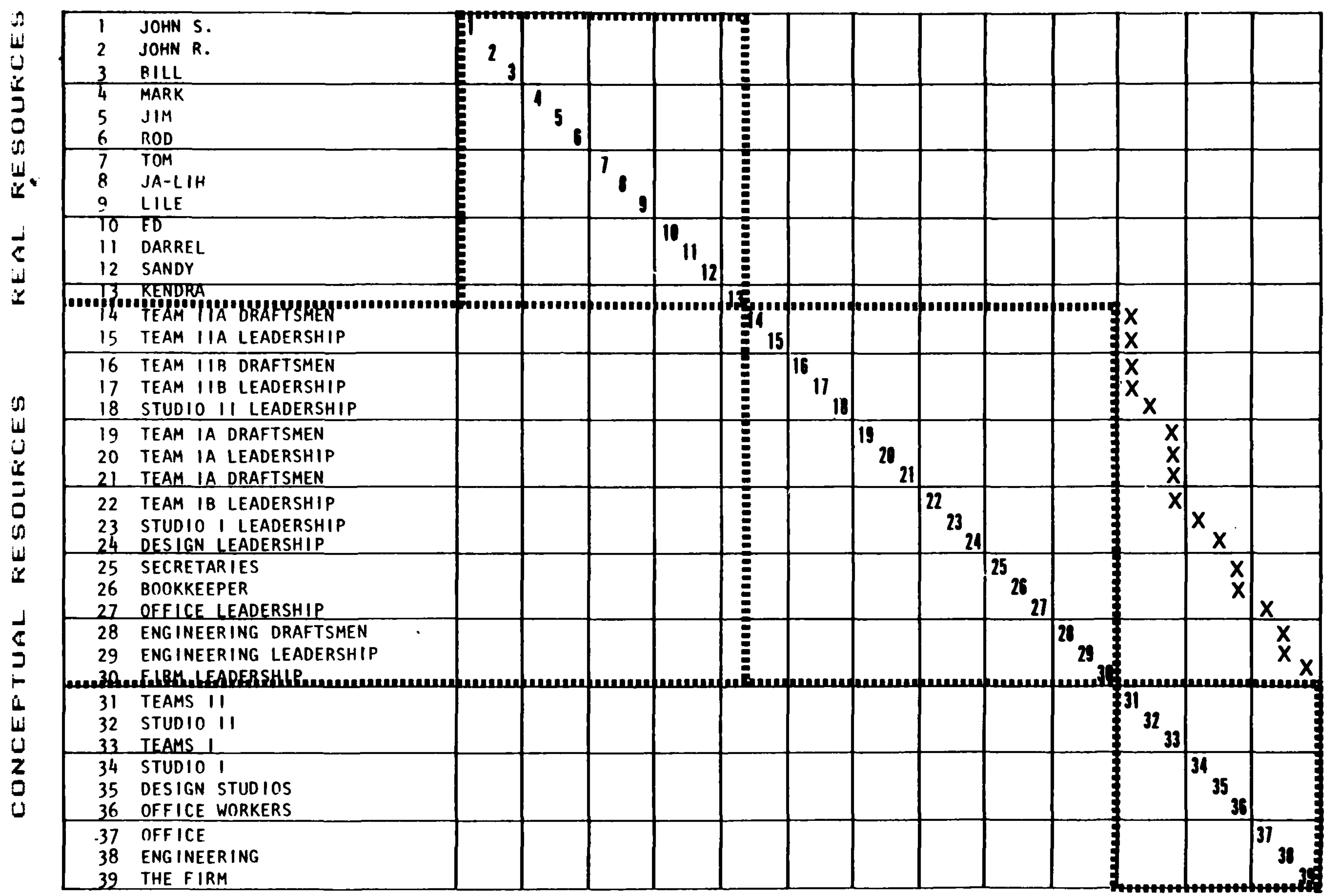


Figure 6-8

ORGANIZATION OF STUDY FIRM: CONCEPTUAL STRUCTURE

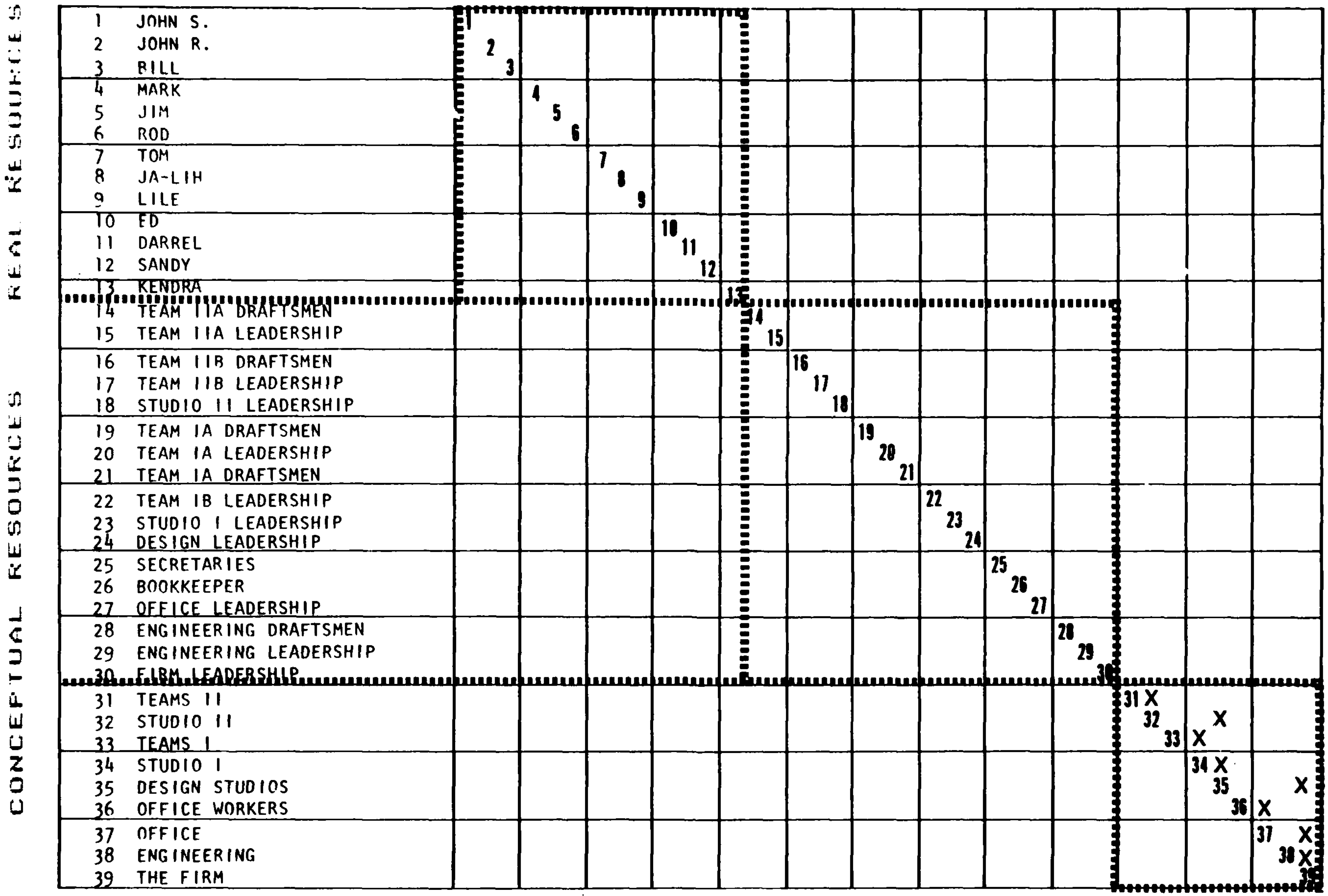


Figure 6-9

6.3.2. Resource-Task Relationships

The tasks normally performed by one employee, Mark, and which are representative of those performed by others in the firm, are listed in Table 6-1, where each is assigned an identifying number. The input required for each task and the output from each task, separated by a slash, /, are listed in Table 6-2.

Figure 6-10 shows a segment of the task-task (T-T) submatrix for <u>those tasks assigned to Mark</u>, i.e., a Resource-Task (R-T) relationship. The R-T submatrix (not shown here) would indicate a positive relationship (assigned to) between Mark's role assignment to "Team IIA Draftsmen" and the 29 tasks shown in Table 6-2. Figure 6-10 indicates with vertical arrows those tasks which receive input from others, and with horizontal arrows those tasks which provide output to others. The round black spots within the matrix show internal input (columns) and output (rows) to the set of Mark's tasks.

6.4. Summary

The figures and tables in this chapter have demonstrated that it is feasible to depict binary resource and task relationships, using the model developed in Chapter 4. The basic data for these figures was developed in the field through interview techniques, and directly transferred to the matrices.

7. Conclusions

The experimental and theoretical work reported herein has shown that

1. the basic matrix model was a good beginning to a comprehensive formal model of purposive human organizations,

TABLE 6-1

MARK'S TASKS

1	draw construction documents
3	change construction documents
4	receive information regarding changes
5	seek affirmation with Tom (project architect)
6	coordinate drawings with technical consultants
	perform building survey
7	physically review project with principals and consultants
8	fill out information forms
9	alter form where needed
10	create new forms
11	summarize forms at end of project
	periodic meetings with principal on the site
27	drawing construction documents
12	review project manual/program
13	if existing building, explore site
14,28	call consultant and/or send marked print
	meet with consultant
2	compile presentation materials planning
15,29	run plate maker and printing machines
16	collate written documents and drawings
17	draw graphics
	file (project files)
18,19	keep own project file
20	review existing project file
21	submit information to correspondence and transmittal files
22	summarize and condense files
	share project information with new draftsmen
23	make field measurements
24	take notes
25	take pictures

TABLE 6-2
INPUT AND OUTPUT
for
MARK'S TASKS

1. Job Captain's Knowledge of Project, Construction Document Sketches/Consultant's Knowledge of Construction Document Changes, Consultant's Knowledge of Project, Approved Construction Document Changes

2. Planning Pictures, Approved Planning Reports, Planning Drawings/Finished Planning Reports

3. Draftsman's Knowledge of Construction Document Changes, Old Construction Document Drawings/ New Construction Document Drawings

4. Job Captain's Knowledge of Construction Document Changes/Draftsman's Knowledge of Construction Document Changes

5. New Construction Document Drawings/Approved Construction Document Drawings

6. Draftsman's Knowledge of Project/Consultant's Knowledge of Project

7. Principal's Knowledge of Project, Consultant's Knowledge of Project/Draftsman's Knowledge of Project

8. Corrected Site Survey Forms/Finished Site Survey Forms

9. Blank Site Survey Forms/Corrected Site Survey Forms

10. Draftsman's Knowledge of Project/Blank Site Survey Forms

11. Finished Site Survey Forms/Summarized Site Survey Forms

12. Project manual/Draftsman's Knowledge of Project

13. Draftsman's Knowledge of Project/Draftsman's Knowledge of Field Conditions

14. Marked Construction Document Print/Consultant's Knowledge of Construction Document Changes

15. Planning Drawing/Planning Drawing, Planning Print

16. Planning Print, Approved Planning Report, Planning Graphics/Finished Planning Report

17. Planning Pictures/Planning Graphics

18. Field Notes/Filed Field Notes

19. Field Measurements/Filed Field Measurements

20. Filed Field Notes, Filed Field Measurements/Filed Field Notes, Filed Field Measurements, Draftsman's Knowledge of Project

21. Mail/filed mail

22. Filed Field Notes, Filed Field Measurements/Summarized Field Notes and Summarized Field Measurements

23. Draftsman's Knowledge of Field Conditions/Field Measurements

24. Draftsman's Knowledge of Field Conditions/Field Notes

25. Draftsman's Knowledge of Field Conditions/Field Condition Pictures

26. Job Captain's Knowledge of Single Project, New Construction Document Drawings/Job Captain's Knowledge of Construction Document Changes, Old Construction Document Drawing

27. Draftsman's Knowledge of Project, Construction Document Sketches/New Construction Documents Drawings

28. Draftsman's Knowledge of Construction Document Changes, Construction Documents Prints/marked Construction Document Prints

29. Approved Construction Document Drawing/Construction Document Prints

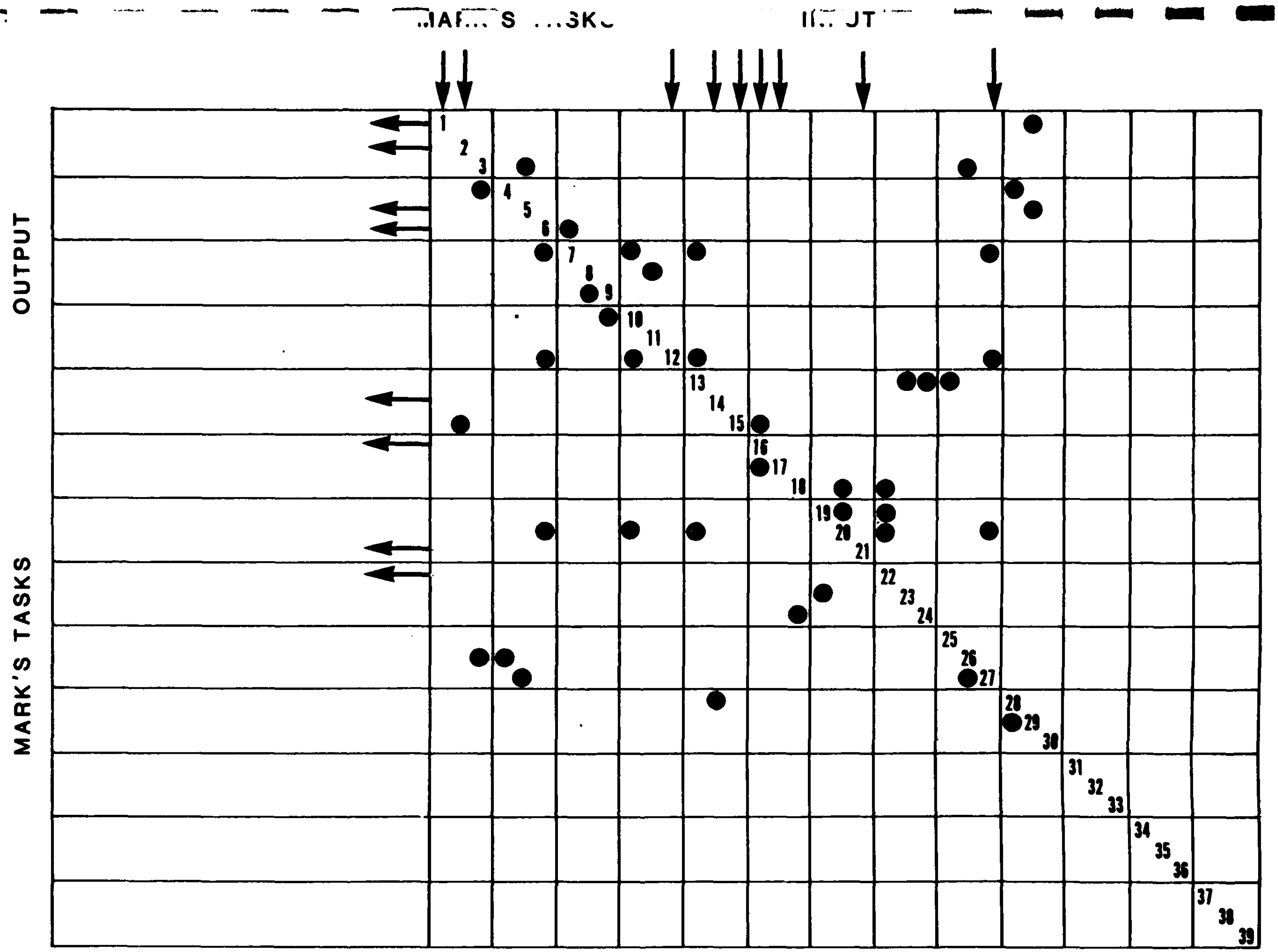

OUTPUT
MARK'S TASKS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39

Figure 6-10

2. in order to adequately depict essential relationships in an organization, it was necessary to expand the basic model, but it was not necessary to change its basic character,

3. it was possible to collect relevant relational data from an existing purposive organization with ordinary interview techniques,

4. the collected data could be transformed readily into the matrix format of the expanded model, to depict a variety of relational patterns existing within the study organization, and

5. the technology evolving from the study promises to be valuable in the diagnosis of organizational pathologies and in the design of new organizations.

The limitations imposed on the study by time and resources did not permit the use of the developed matrices, as planned, in the re-examination of the firm, to assess the degree of misunderstandings about role, tasks, responsibilities, etc. A thorough examination of the firm, with matrices for each employee, every task, and every conceptual resource would have required substantially more time and effort than expected. The tools to do so, however, are now at hand and are being formalized.

8. Recommendations

The expanded model is a viable foundation on which to construct a comprehensive static organization model. It can be extended to include dynamic capabilities, and this should be done. The potential returns from such a model far exceed the probable costs.

9. References

1. Dinnat, R. M., and Murphree, E. L., "A Technique for Modelling Building Organizations," Proceedings of the International Symposium on Construction Organization and Management, Haifa, Israel, September, 1978.

2. Ansoff, H. I., and Brandenburg, R. R., "A Language for Organization Design: Parts I and II," Management Science, Vol. 17, No. 12, August, 1971.

3. Galbraith, Jay R., Organization Design, Addison-Wesley Publishing Co., Reading, Mass., 1977.

4. Dinnat and Murphree, ibid.

5. Dinnat and Murphree, ibid.

6. Davis, S. M., and Lawrence, P. R., Matrix, Addison-Wesley Publishing Co., Reading, Mass., 1977.

Biographies

E. LILE MURPHREE, JR., is a graduate of the University of Mississippi (BSCE, MA in Mathematics), the Massachusetts Institute of Technology (SM in Civil Engineering) and the University of Illinois at Urbana-Champaign (Ph.D. in Civil Engineering Systems). He has held faculty appointments in Mathematics, Civil Engineering, Industrial Engineering, and Architecture. A Division Chief at the U. S. Army Construction Engineering Research Laboratory from 1969 to 1975, he is now President of Sage Systems Corporation, Urbana, IL, and Visiting Research Professor of Architecture, University of Illinois, Urbana-Champaign.

ROBERT M. DINNAT is a graduate of the Louisiana State University (BFA), the Georgia Institute of Technology (Bachelor of Architecture, MS and Ph.D. in Civil Engineering) and the University of Illinois at Urbana-Champaign, MBA). He has held faculty positions in Civil Engineering and Architecture. From 1970 to 1979, he was a Division Chief at the U. S. Army Construction Engineering Research Laboratory; since 1979, he has been Associate Technical Director there. Dr. Dinnat is also Adjunct Professor of Architecture, University of Illinois, Urbana-Champaign. A full-time federal employee, Dr. Dinnat contributed time outside of his normal working hours to the project reported here.

PATRICIA A. CLICKENER is a graduate of the University of Washington, Seattle (BA), and the University of Illinois (M. Arch., MBA). She has held positions in university teaching, banking and brokerage, pharmaceutical sales and research, the latter with the American Institute of Architects Research Foundation. Her awards and honors include a National Federation of Women Scholarship and an AIA Foundation Scholastic Award.

RICHARD MATTHEWS is a graduate of the University of Kansas (Bachelor of Environmental Design, with Highest Distinction; Bachelor of Architectural Engineering, with Distinction), and will, in December 1981, graduate from the University of Illinois, Urbana-Champaign (M. Arch., MBA). In 1975, The Ewart Scholarship allowed Mr. Matthews to study architecture for a year at Heriot-Watts University, Edinburgh, Scotland. He has been a designer with Design Associates, Amarillo, TX, and has held research positions at the University of Kansas and the National Bureau of Standards. A private pilot and a violinist, he has also had experience in building and programming digital computers.

END

DATE FILMED

12-81

DTIC